United States
Department of
Agriculture

Forest Service

**Rocky Mountain
Forest and Range
Experiment Station**

Fort Collins,
Colorado 80526

**General Technical
Report RM-GTR-272**

Desired future conditions for Southwestern riparian ecosystems: Bringing interests and concerns together

September 18-22, 1995
Albuquerque, New Mexico

Shaw, Douglas W. and Deborah M. Finch, tech coords. 1996. Desired future conditions for Southwestern riparian ecosystems: Bringing interests and concerns together. 1995 Sept. 18-22, 1995; Albuquerque, NM. General Technical Report RM-GTR-272. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 359 p.

Abstract

This proceedings represents scientific and applied papers presented at a symposium of the same title held 18-22 September 1995 at the Four Seasons Hotel in Albuquerque, New Mexico. The symposium brought together scientists, natural resource managers, conservationists, and representatives from the private sector to share their findings, ideas, and visions for managing, conserving, and restoring riparian ecosystems in the Southwest. The Proceedings is divided into sections on the history, ecology, and management of the Rio Grande; general ecosystem hydrology and ecology; human history, values, and needs; ecosystem restoration and species recovery; and current and desired future conditions. Oral presentations given during panels on "Rio Grande restoration" and "People and riparian ecosystems" are also published in this volume. Patricia Pettit, President of the New Mexico Riparian Council, closed the symposium with an interactive session with the audience, which is summarized and published here. We thank sponsoring organizations for their support, and Karen Mora for her assistance in publishing the proceedings.

Keywords: Riparian ecosystems; desired future conditions; human dimensions; hydrology; ecology; history; restoration; species recovery.

Compilers' Note: In order to deliver symposium proceedings to users as quickly as possible, many manuscripts did not receive conventional editorial processing. Views expressed in each paper are those of the author and not necessarily those of the sponsoring organizations or the USDA Forest Service. Trade names are used for the information and convenience of the reader and do not imply endorsement or preferential treatment by the sponsoring organizations or the USDA Forest Service.

Cover photo: Verde River near Perkinsville, Arizona

USDA Forest Service
General Technical Report RM-GTR-272

March 1996

Desired future conditions for Southwestern riparian ecosystems: Bringing interests and concerns together

September 18-22, 1995
Albuquerque, New Mexico

Technical coordinators:

Douglas W. Shaw
USDA Forest Service, Region 3
Albuquerque, New Mexico

Deborah M. Finch
USDA Forest Service
Rocky Mountain Forest and Range Experiment Station
Albuquerque, New Mexico[1]

Sponsors:

New Mexico Riparian Council

Tree New Mexico

New Mexico State Land Office

USDI Fish and Wildlife Service

USDA Natural Resource Conservation Service

USDA Forest Service, Region 3

USDA Forest Service, Rocky Mountain Forest and Range Experiment Station

[1] *Headquarters is in Fort Collins, in cooperation with Colorado State University.*

Contents

Page

Opening

Rio Grande history, ecology, and management

(Continued)

Ecosystem hydrology and ecology

Human history, values, and needs

(Continued)

Ecosystem restoration and species recovery

Current and desired future conditions

(Continued)

Closing

Appendix

Introduction

Introduction

Douglas W. Shaw[1] and Deborah M. Finch[2]

Interest in the condition, role, and sustainability of southwestern riparian ecosystems has increased greatly since the mid 1970's. Reflecting this growing interest is a series of symposia addressing southwestern riparian issues, including those coordinated by Johnson and Jones (1977), Johnson and McCormick (1979), Johnson et al. (1985), and Tellman et al (1993). The proceedings of these symposia tell an important story about the history of riparian ecosystems, documenting changes in water quality, vegetation, fish and wildlife, land use, and human values. Concern for the declining health of riparian areas, first expressed by the scientific community, has expanded to a much broader spectrum of interest groups including land and water resource managers, educators, recreation managers, sports people, commodity producers, legislators, and environmentalists. All of these people seek information and understanding about the dynamics, functions, uses, and restoration of riparian areas, especially in relation to the quality of human lives and livelihoods.

Scientists and managers are now beginning to implement studies and projects that integrate different perspectives of riparian areas. People representing different disciplines, including the social sciences, are forming study teams to address complex questions. We are starting to acknowledge and manage for humans as an integral, influential component of riparian ecosystems by planning their needs, effects, and conflicts into our projects. In addition, new data, ideas, and technology from more traditional sciences such as biology and hydrology are being generated and modeled with computer programs at incredible rates, propelling science beyond the boundaries of existing knowledge into a new age of information explosion.

This symposium on "Desired Future Conditions for Southwestern Riparian Ecosystems: Bringing Interests and Concerns Together" was intended to provide a forum to exchange ideas and information on riparian ecosystem management, with a new emphasis on human values, needs, and roles. Participation by government agencies, universities, land managers, environmental groups, American Indian people and private land owners was invited by the Steering Committee for the symposium. We actively sought speakers from a variety of disciplines to round out the more typical slate of presentations to achieve a broader understanding and review of riparian ecosystems.

The Honorable Walter Bradley, Lieutenant Governor of New Mexico, in his opening comments, challenged us to include an even broader spectrum of people in our knowledge sharing. He also recommended that we share information in a common language that all users and interest groups could understand. Based on the positive comments that we heard from audience participants, we are confident that useful and pertinent information was successfully shared and understood during the symposium and field trip, and that this publication will help spread this knowledge to a broader audience.

LITERATURE CITED

Johnson, R. Roy and Dale A. Jones, tech. coords. 1977. Importance, Preservation and Management of Riparian Habitat: A Symposium. Tucson, Arizona. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. General Technical Report RM-43.

[1] *Hydrologist, USDA Forest Service, Southwestern Region, 517 Gold Ave. SW, Albuquerque, NM 87102.*

[2] *Project Leader, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, 2205 Columbia SE, Albuquerque, NM 87106.*

Johnson, R. Roy and J. Frank McCormick, tech. coords. 1979. Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems, Proceedings of a Symposium. Callaway Gardens, Georgia. USDA Forest Service, Washington, D.C., General Technical Report WO-12.

Johnson, R. Roy, C. D. Ziebell, D. R. Patton, P. F. Ffolliott, R. H. Hamre, tech. coords. 1985. Riparian Ecosystems and Their Management: Reconciling Conflicting Uses. Tucson, Arizona. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. General Technical Report RM-120.

Tellman, Barbara, H. J. Cortner, M.G. Wallace, L. F. DeBano, R. H. Hamre, tech. coords. 1993. Riparian Management: Common Threads and Shared Interests, A Western Regional Conference on River Management Strategies. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. General Technical Report RM-226.

Rio Grande history, ecology, and management

Letter by Senator Pete Domenici

Pete V. Domenici[1, 2]

Thank you for your invitation to attend today's panel discussion on "Rio Grande Restoration: Future Directions." I apologize for not being able to attend in person, but I hope you will understand that now is a particularly busy time here in Congress.

As we all know, the Rio Grande is synonymous with life in New Mexico. It is this basic fact that makes today's discussion so important. Our State depends on the Rio Grande for so much—for basic water resources, for riparian wildlife habitat, for simple aesthetic beauty—that we simply must make the best decisions about how we use and protect it. Fortunately, recent years have seen important progress being made in crafting policies that will restore and preserve the Rio Grande.

I have tried to help in this regard. For example, I have been involved in the ongoing bosque preservation initiative since 1991, and am happy to say that the Senate has recently approved a $500,000 appropriation to aid in the implementation of recommendations made by the Rio Grande Bosque Conservation Committee. Another $940,000 was also approved by the Senate, at my request, for much-needed rehabilitation of the Bosque del Apache Wildlife Refuge. This money will be used for such projects as a new service and storage facility, replacement of obsolete heavy equipment, and rehabilitation of road and water delivery systems. Finally, the Senate has approved my request for $1 million to continue the U.S. Geological Survey's comprehensive study of the availability of water in the Middle Rio Grande Basin.

Money alone, however, will not solve the problems facing the Rio Grande, and that is why today's conference is so very important. To make lasting progress on Rio Grande restoration, there must also be full and sustained coordination at all levels—federal, state, county, and local. Only in this way, with all of us working together, can we ensure the protection, preservation, and enhancement of this most precious resource.

[1] *United States Senate, Washington, DC 20510-3101.*

[2] *Presented by Staff Representative, Cheryl Garcia.*

The Middle Rio Grande: Its ecology and management

Jeffery C. Whitney[1]

Abstract.—The Middle Rio Grande (MRG) riparian forest, or "bosque", represents the largest cottonwood gallery riparian forest in the southwestern United States. This reach of the Rio Grande extends from Cochiti Dam downstream 260 Km to San Marcial, New Mexico. It constitutes 8% of the river's total length and 34% of if its length in New Mexico. The valley traverses three major biotic communities, as defined by Brown and Lowe (1980). The MRG reach can be subdivided into 4 reaches which coincide roughly with the 4 geologic basins or "grabens" along this portion of the Rio Grande Rift. This system has been affected by man's activities throughout prehistoric and modern eras. The Rio Grande is regulated for water supply (primarily irrigation) and flood control. The effects of this interaction have contributed to the character of the riparian ecosystem in its current expression. Over 40% of New Mexico's population lives within the MRG reach. This paper will discuss the climate, geology, hydrology, subsequent river morphology, and anthropogenic factors which contribute to the past and current expressions of the riparian habitat associated with the Middle Rio Grande.

INTRODUCTION

The Rio Grande is one of the longest rivers in North America (1900 miles). The Rio originates in the southern Rocky Mountains of Colorado, flows the whole length of New Mexico and forms the entire border between the state of Texas and the Republic of Mexico (fig. 1). The Rio is the greatest source of permanent water in the desert southwest other than the Colorado River. It is home to the largest cottonwood forest in North America, locally referred to as the "Bosque".

Human populations have increased dramatically along the Rio Grande since European settlement. Human use of water for irrigation and consumption, and human use of land for agriculture, urban centers, livestock grazing and recreation have changed Rio Grande ecosystems by altering flood cycles, channel geomorphology, upslope processes, and water quality and quantity. Such abiotic changes have influenced the biological diversity and ecological functions of the MRG, altering the distribution, structure, and composition of riparian plant and animal communities.

The Rio Grande basin above El Paso, Texas, is one of the oldest regions of agriculture in the United States. Agricultural activity extends back centuries to prehistoric inhabitants of the Rio Grande valley (fig. 2.) and includes the seventeenth and eighteenth century Pueblo Indians and Spanish colonists, and European-Americans in the latter part of the nineteenth century (Wozniak 1987). More recent history of the region involves disputes and concerns over management, irrigation, and distribution and delivery of upstream waters to downstream users in an attempt at fair sharing between concerned parties. Because of the

[1] *Middle Rio Grande Coordinator, U.S. Fish and Wildlife Service, Albuquerque, NM.*

long history of agricultural activity , Rio Grande water is tied to public laws governing its conveyance, storage, and use. The close connection between legislation and flow of water through the Rio Grande is largely responsible for the present physical state of the river, floodplain, and associated riparian community. Changes in the floodplain ecology probably began shortly after human settlement in the region, and change has continued relatively unabated with increasing population. (Bullard and Wells 1992).

LOCATION

The MRG is part of the larger Rio Grande fluvial system (fig. 1). The Rio Grande headwaters lie along the Continental Divide at elevations ranging from 2,440 m to 3,660 m in the San Juan Mountains of southern Colorado. The entire area of the Rio Grande drainage basin is about 470,000 sq. km of which about 230,00 sq. km. are in the United States and the remainder in Mexico (Hunt, 1974). The river flows south from Colorado through the length of New Mexico and then forms the international boundary between Texas and the Republic of Mexico. The drainage basin area above Elephant Butte is about 76,275 sq. km., including 7,615 sq. km. in the Closed Basin of the San Luis Valley in Colorado. Above Velarde the drainage basin area is about 27,325 sq. km., including the Closed Basin. The Rio Chama, one of the most important tributaries in the study area, has its headwaters in the Jemez, Conejos, and San Juan Mountains of New Mexico and Colorado. The MRG extends from Cochiti Dam downstream 260 river km (160 mi) to San Marcial (fig. 3). The MRG constitutes 8% of the River's total length and 34% of its length in New Mexico. The middle valley's direct drainage accounts for 7% of the total Rio Grande drainage and about half of New Mexico's direct tributary drainage.

PHYSIOGRAPHY AND GEOLOGY

Hydrologic characteristics of the Rio Grande Basin, such as infiltration, runoff, and sediment discharge, are dependent on the geology, geomorphic evolution of tributary basins and late Tertiary and Quaternary geologic and climatic history. Structural geology (such as faults and folds) of a region governs spatial and geometric relations of rock units in that region. Geologic structures and lithology influence the development of topographic features, river and tributary position, and landscape evolution. Tectonic activity can produce measurable effects on channel and sediment transport characteristics (Ouchi 1983, 1985; Schumm 1986).

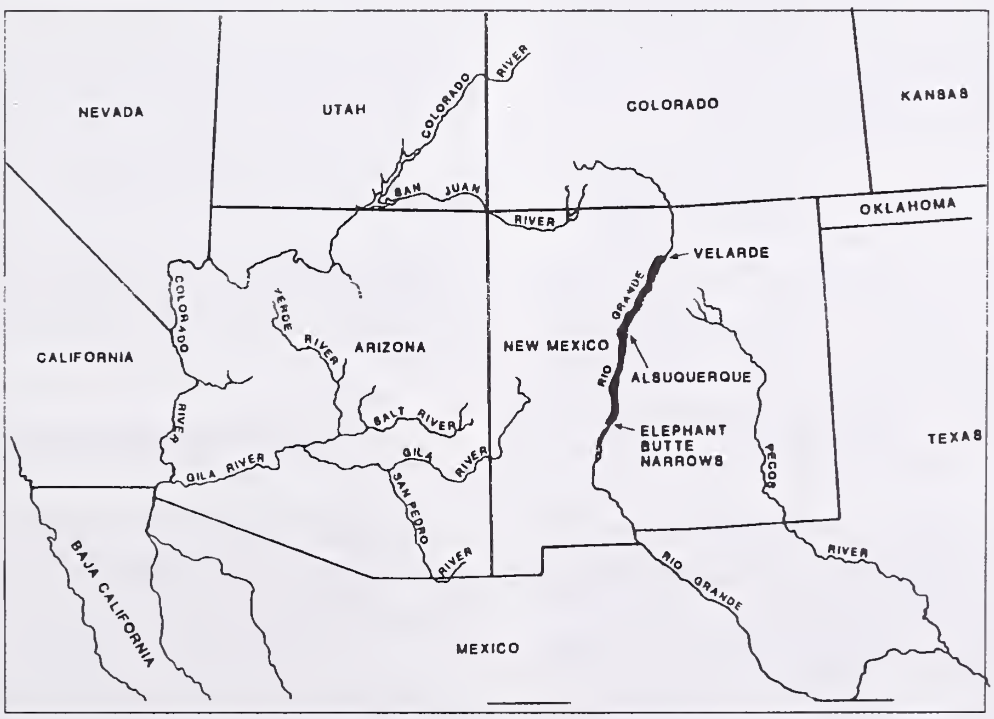


Figure 1. Middle Rio Grande study area (from Bullard and Wells, 1992).

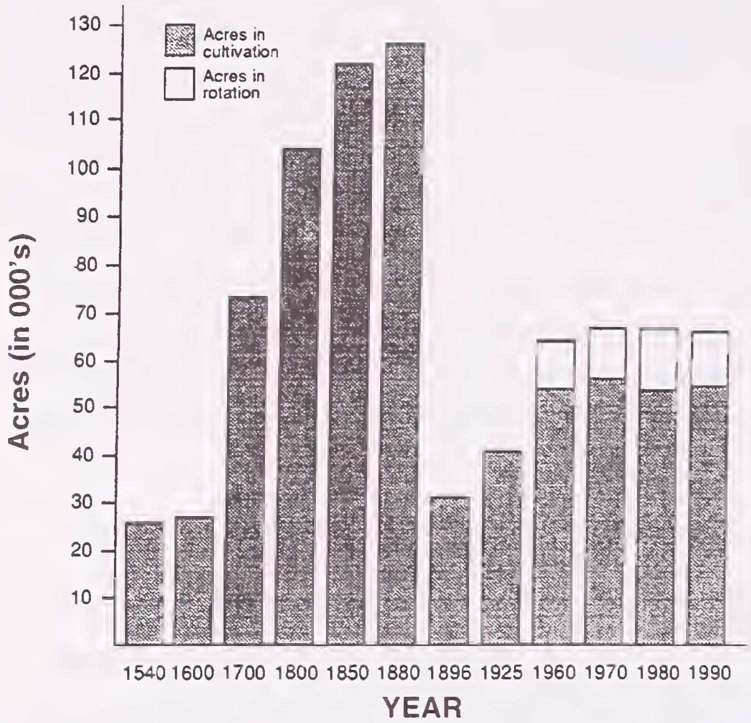


Figure 2. Historical account of acres of land under cultivation in the Middle Rio Grande Valley (acres/ 2.47=hectares) (From Crawford et al, 1993).

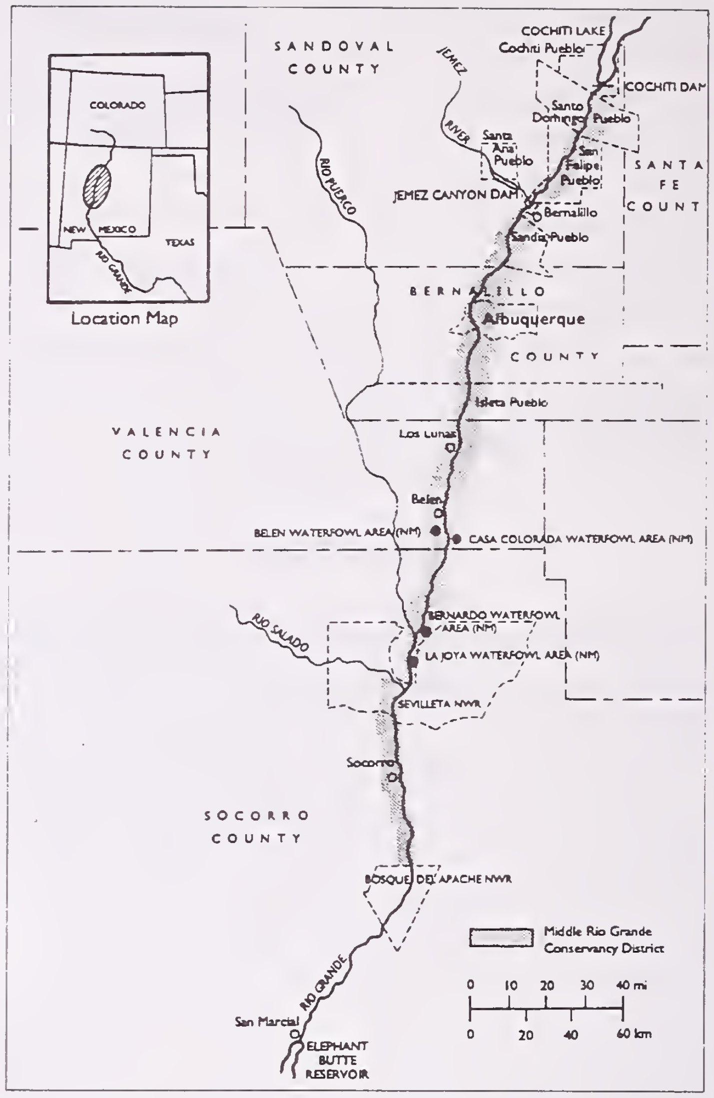


Figure 3. Setting and institutional boundaries in the Middle Rio Grande (from Crawford et al, 1993).

The location of the Rio Grande is controlled by the dominant geologic structure of the region, the Rio Grande Rift. The Rio Grande Rift is a linear topographic feature that separates the Great Plains from the Colorado Plateau (Hawley 1978) mountain ranges, which can influence weather patterns, are a direct result of geologic processes. The rift, active for at least 18 million years (Wilkins 1986), is characterized by extension, seismicity, local tectonic uplift, and volcanism (Loainski et al. 1991). The location of early trade routes was influenced by the spatial arrangement of mountain ranges that were natural barriers to travelers. Indigenous populations and early settlers in the region sought areas of suitable climate, access, and availability of water. Thus, the presence of the Rio Grande Rift has influenced human settlement patterns in the region.

The extent and type of bedrock can influence infiltration and runoff characteristics. These factors can dramatically influence tributary basin evolution, discharge characteristics, main stem flow, and main stem evolution and integration (Leopold et al. 1964; Schumm 1977; Richards 1982; Kelson 1986; Wells et al. 1987, Bullard and Wells 1992). Bedrock type influences vegetation types and densities, which in turn influence infiltration and runoff, landscape stability, soil development, and sediment supply. Soil development is important because natural, progressive changes in physical properties of soils occurring through time alter the nature of the land surface, including vegetation communities, infiltration (decreases with increasing age), erosion, and runoff and discharge.

PHYSIOGRAPHIC REGIONS

The Rio Grande basin lies in five physiographic provinces: the Coastal Plain, the Great Plains, the Basin and Range, the Colorado Plateau, and the Southern Rocky Mountains (Hunt 1974). The MRG and its tributaries are located within the latter three provinces. From about Santa Fe southward, the rift is in the Basin and Range Physiographic Province which separates the Colorado Plateau

Province to the west from the Great plains Province to the east. (Crawford et al. 1993).

The MRG valley is actually a series of basins. These grabens (depressions) formed a series of linked, but slightly offset, depositional basins, each of which contained its own ephemeral lake. Over time, the surface water eroded canyons between the intervening bedrock sills that defined the basins, integrating the area into the Rio Grande river system (Bullard and Wells 1992). The through-flowing ancestral Rio Grande drainage developed into a single river about 5 million years ago (Lozinski et al. 1991). The basins in the Middle Rio Grande are:

- Santo Domingo Basin
- White Rock Canyon to San Felipe
- Albuquerque Basin
- San Felipe to Isleta
- Belen Basin
- Isleta to San Acacia
- Socorro Basin
- San Acacia to San Marcial

CLIMATE

The hydrology and morphology of the Rio Grande are ultimately dependent on the climate and geology of the area. An overview of these topics will create a foundation of understanding for later discussions.

The valley's climate is characterized as having moderate temperatures and being semiarid above Bernalillo to arid south of Bernalillo (Tuan et al. 1973). Temperatures increase and precipitation decreases from north to south. Annual average maximum temperatures, which usually occur in July, range from 21°C (69°F) at Cochiti Dam to 24°C (76°F) at Bosque del Apache National Wildlife Refuge (NWR). Annual average minimum temperatures (January) are about 4°C (40°F) throughout the valley. The growing season also increases southward through the valley. In Bernalillo and Albuquerque, the typical frost-free period begins in early May and extends through mid-October, lasting on average 160 days. In Socorro, the average period is 197 days, beginning in Mid-May and lasting through late October.

The Rio Grande drainage basin is located in a transitional climatic zone between the Gulf of Mexico and the Pacific rainfall provinces. Complex meteorological conditions exist in this region, and these conditions are further complicated by the orographic influence of surrounding mountain ranges and global circulation patterns.

The MRG basin has an arid to semiarid climate typical of the southwestern United States. The climate is characterized by abundant sunshine, low relative humidity, light precipitation, and wide diurnal temperature fluctuations. The average annual precipitation varies from 178 MM (7 in.) to 380 mm (15.25 in.) over two-thirds of the basin and may exceed 635 mm (25 in.) only in the high mountain areas. Winters are generally dry, and snow rarely remains on the ground at low elevations for more than 24 h. Snowfall in the high mountains composes 30-75% of the total annual precipitation; in the remainder of the basin snowfall composes less than 25% of the annual precipitation. Summer precipitation supplies almost half of the annual moisture. Most of the rain falls in brief, though sometimes intense, convective thunderstorms (fig. 4). These summer thunderstorms have a considerable moderating effect on daytime temperatures. Prevailing winds are from the southwest and typically are continuous during the spring months. Evaporation rate is high throughout the lower elevations of the basin and is highest in the southern part of the basin, where arid conditions exist.

Storms in the region are of two types; local thunderstorms that result from orographic or convective lifting, and frontal storms resulting from the interaction of two or more air masses. Generally, precipitation during storm periods lasts less that 24 h, although precipitation intensity may be extremely high at some locations within the general storm area. Precipitation periods lasting more than 24 h are generally associated with tropical disturbances related to hurricane activity in the Gulf of Mexico or in the Pacific Ocean off the west coast of Mexico.

Storms are seasonal with respect to type and magnitude. Summer months, June through August, are normally characterized by intermittent

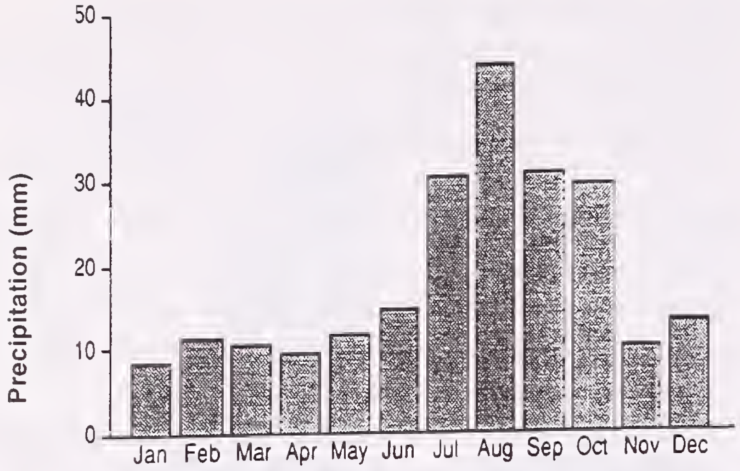


Figure 4. Monthly average precipitation distribution in the Middle Rio Grande Valley (after Crawford et al, 1993).

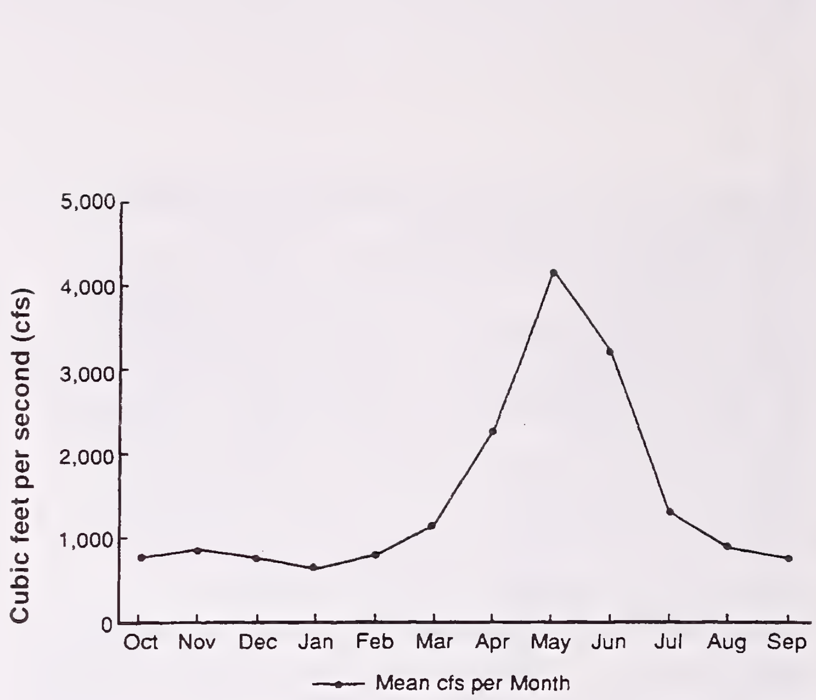


Figure 5. Mean monthly discharge in cubic feet per second (cfs) of the Rio Grande at the Otowi gauge above Cochiti Lake (U.S. Geological Survey data, 1895-1991).

importations of tropical maritime air masses. Orographic lifting or convective action results in isolated shower activity, which is often intense but generally localized.

Vigorous air-mass activity occurs during winter months, November through February, and is characterized by a series of cold fronts of polar Pacific air moving eastward or northeastward (Maker et al. 1972). This results in snow in the higher elevations and rain in the lower elevations. Due to the northerly path of the storms precipitation in the southern part of the basin is generally low.

The periods transitional to summer and winter (March through May and September through October) are associated with some of the largest flood-generating storms. Greater temperature differences between air masses are reflected in increased air-mass instability.

Runoff in the basin comes largely from spring snowmelt and spring and summer convective thunderstorms; it ranges from <25 mm (1 in.) to >255 mm (10 in.) in the mountains. About 70% of the runoff occurs from May to August during snowmelt and thunderstorm activity (fig. 5).

FLUVIAL CHARACTERISTICS

The physical nature of the Rio Grande, and its tributaries, varies with its position in the drainage basin. This is a direct reflection of the geology and topography of the physiographic regions traversed by the river. Gradient, channel pattern and width, discharge, and sediment load are variable throughout the length of the river. Discharge and sediment load characteristics will be discussed in more detail in separate sections.

GRADIENT OF THE RIO GRANDE

Relief is high in headwater regions, and tributary streams characteristically flow through steep canyons on their way to the San Luis Valley; gradients locally may be tens of meters per kilometer. The river has a gradient of about 0.56 m/km through the San Luis Valley. Through the Rio Grande Gorge, river slope ranges from 2.25 to >28.4 m/km. From Velarde to Cochiti Reservoir the downstream end of White Rock Canyon) river gradient is about 1.9 m/km. From below Cochiti Dam to Elephant Butte the gradient is about 0.76 m/km.

CHANNEL OF THE RIO GRANDE

The channel of the Rio Grande varies dramatically with geographic location within the river basin. Channel characteristics such as width and sinuosity are strongly influenced by position within the drainage basin and proximity to tributaries that discharge large volumes of sediment into the main stem.

The width of the Rio Grande Valley ranges from <200 m (656 ft.) in the Rio Grande Gorge to 1.5-10 km (1-6 mi) from Velarde to Elephant Butte, with the exception of White Rock Canyon and the San Marcial Constriction. Short canyons or narrows also exit at San Felipe, Isleta, and San Acacia at the boundaries of the sub-basins within the Rio Grande Rift The floodplain of the Rio Grande ranges from 150 m (492 FT) or less in the Rio Grande Gorge to greater than 1 km (.62 mi) in the reaches from Velarde to White Rock Canyon and from Cochiti Dam to San Acacia.

The channel is narrowest in the bedrock canyons and widest in the broad alluvial valleys downstream from Bernalillo. Generally, the channel is 60-90 m (196-295 ft) wide, flows on shifting sand and gravel substratum, and has low, poorly defined banks (Lagasse 1980). Within the MRG the floodway is largely confined between earthen levees and is cleared for much of the length, especially in urban areas and areas prone to highest aggradation. The floodplain contains a mixture of cottonwood (*Populus Fremontii*), willow (*Salix spp.*), Russian-olive (*Elaeagnus angustifolia*), and salt cedar (*Tamarix chinensis*), which together form a dense growth of riparian woodland (known as bosque), interspersed with pasture and cultivated land (Lagasse 1981). The existing contiguous bosque that abuts the Rio Grande is generally limited by the system of levees or natural bluffs where such features are present. In the southern half of the valley where the bosque is at its widest, the bosque is up to 4-5 km (2.5-3 mi) wide.

The Middle Rio Grande is slightly sinuous with straight, meandering, and braided reaches. The river is generally characterized by a shifting sandbed in the reaches and by a gravel riverbed in the Cochiti Reach. Although a perennial river, there are reaches of the Rio Grande that experience no surface flow during some summer months in dry climatic periods (Crawford et al. 1993). The formation of sediment bars in the channel during low-flow periods and, in particular, during the recession of flood flows, together with rapid growth of vegetation, generally determine the channel configuration within the levees. In some places the floodway is unstable (i.e. the channel is not confined to a fixed position). In these areas, the channel has virtually no banks, and the bed of the river is at or above the land surface outside the levees due to sediment deposition between the levees. Braided meandering patterns are especially common downstream from major sediment-supplying tributaries such as the Rio Puerco and the Rio Salado and other small, unregulated, high-sediment-discharge tributaries in the reach below Cochiti Dam.

The addition of numerous flood control and sediment control structures on the Rio Grande and tributaries has eliminated some of the problems formerly associated with flood-transported sediment discharged into the main stem. On the other hand, flood control structures have added to the problem of channel migration in some reaches of the river downstream of dams (Lagasse 1980,1981; Bullard and Wells 1992).

DISCHARGE OF THE RIO GRANDE

The Rio Grande is a perennial river that receives the majority of its discharge from late spring snowmelt and rain storms. Summer convective storms produce runoff in isolated parts of the basin, which may alter the hydrology for brief periods.

The majority of the discharge for the MRG comes from the headwaters of the Rio Grande in Colorado and from the Rio Chama. The Rio Chama joins the Rio Grande 35 miles north of Cochiti Reservoir. The Rio Chama is assured of perennial discharge because of the San Juan-Chama Transmountain diversion (SJC) Project and dams along the Rio Chama and its tributaries (U.S. Bureau of Reclamation 1981). Average annual discharge for the Rio Grande into the Gulf of Mexico is about 9,000,000 acre-feet (Hunt 1974). The annual runoff in headwater regions ranges from 215,000 to 1,100,000 acre-feet, with and average of 660,000 acre-feet (U.S. Corps of Engineers 1989).

The Rio Grande has some of the longest stream gaging records in the United States; however, these records are not necessarily the most reliable (Bullard and Wells 1992). The Embudo gage near the southern end of the Rio Grande Gorge was installed in 1889 and has nearly 100 years of record, although not continuous. Reliability and continuity of stream gaging station data are problems throughout the United States, and The Rio Grande is no exception.

The main stem discharge of the MRG can be characterized by 10 gaging stations: Embudo upstream from Velarde, San Juan Pueblo (discontinued in 1987), Otowi Bridge near San Ildefonso, below Cochiti Dan, San Felipe, Albuquerque, Rio Grande Floodway near Bernardo, RIO Grande Floodway at San Acacia, Rio Grande Floodway at San Marcial, and below Elephant Butte Reservoir. Annual average flow at Otowi Bridge (fig. 6), is about 1,100,000 acre-feet; downstream at San Marcial above Elephant Butte Resérvoir, the annual average flow is 745,000 acre-feet (U.S. Army Corps of Engineers 1989).

Due to extensive agricultural activity in the MRG nearly all Rio Grande water is appropriated. Releases from upstream reservoirs, under non-flood conditions, are regulated to make reservoir outflows equal to inflows in order to meet water demands. Irrigation accounts for about 90% of demands. Irrigation accounts for Rio Grande water used in the region; however, water diverted for agricultural purposes is not fully utilized. About 67% of all diverted water does not reach farmlands. This water consists of transportation losses (spills, seepage losses to unlined canals), evapotranspiration, and groundwater recharge. About 45% of all water diverted eventually returns to the river. About 33% of water diverted reaches the farms; crops use about 55% of this amount (or about 20% of the total diverted from the river). About 35% of the total diverted water is lost to evapotranspiration or groundwater recharge (U.S. Army Corps of Engineers 1979).

SEDIMENT LOAD OF THE RIO GRANDE AND TRIBUTARIES

Suspended sediment loads for the Rio Grande and tributaries are variable. These are regulated to a certain degree by flood and sediment control structures, especially in the regions above Albuquerque. Tributaries, however, can be major contributors of sediment to the Rio Grande. An increase in sediment supplied to the Rio Grande can have dramatic effects on river behavior and geomorphology both upstream and downstream (Schumm 1977; Lagasse 1980,1981).

Based upon data reviewed by Bullard and Wells (1992), the Rio Puerco which has half of the drainage area of that of the Rio Chama and the Jemez River contributes far more sediment than that of

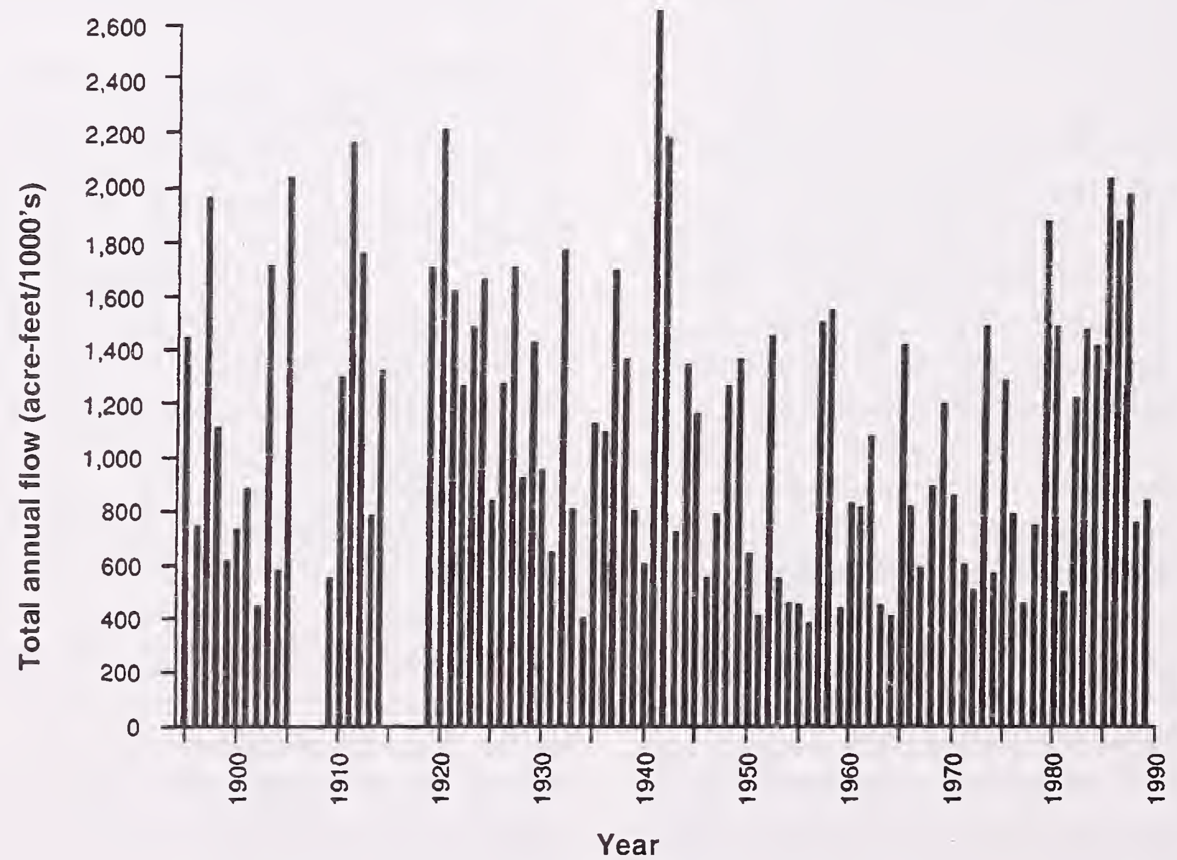


Figure 6. Total annual flow, Rio Grande at the Otowi gauge (from Allen et al, 1993).

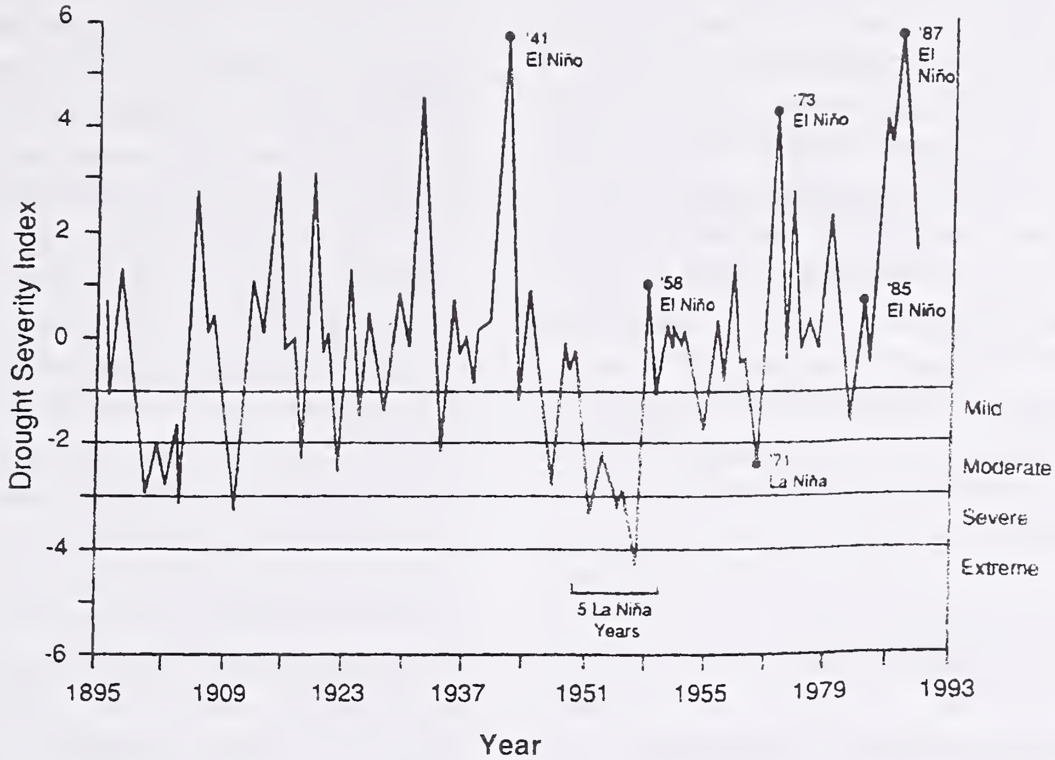


Figure 6a. Drought severity index 1895 through 1988 and El Nina and La Nina events over the past 50 years for the Middle Rio Grande Valley (after U.S. Army Corps of Engineers, 1991).

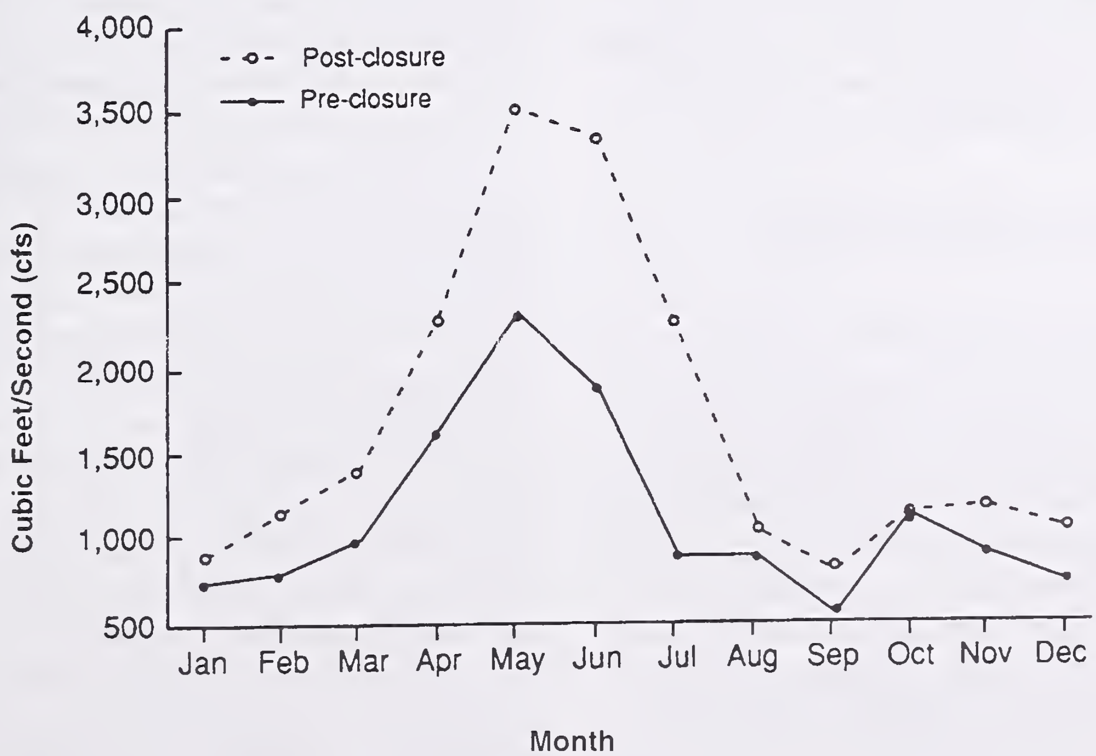


Figure 6b. Fifteen-year average of Rio Grande monthly mean discharge for pre- and post-Cochiti Dam closure periods at San Felipe gauge (from Crawford et al, 1993).

the former. The authors attribute this to the fact that the Chama and Jemez rivers are dammed and the Rio Puerco and Rio Salado are not. The conclusion is obvious and has merit. However, the rationale may be a bit misleading since the character, including soils, elevation, vegetative ground cover of the respective watersheds are not similar. Flow regimes are also very dissimilar in that the Chama is perennial, the Jemez tends to be, and the Rio Puerco lacks discharge of water or sediment for many days of the year (Heath 1983). Leopold found that 82% of the sediment transported by this tributary occurs during events that recur about once per year (Leopold et al. 1964).

CONTAMINANTS

An additional effect related to sedimentation and river siltation is the accumulation of toxic materials in the sediments. Popp et al. (1983) and Brandvold et al. (1984) conducted studies on the sediments of the Middle Rio Grande system. They found that substantial quantities of cadmium, mercury, lead, uranium, and pesticides (18 different concentrations ranging from undetectable to >500 micrograms per liter are being transported by the Rio Grande and deposited in Elephant Butte Reservoir. These materials are primarily bound to sediment, although an unknown amount of cycling from sediments to the water column occurs in the reservoir (Bullard and Wells 1992).

ANTHROPOGENIC FACTORS

Some references have already been made to the anthropogenic factors that have played a role in creating the riparian habitat as currently evidenced by the "bosque" found within the MRG. These structural changes and dewatering combined with the abiotic features previously discussed combine to create a highly modified and controlled system.

Although there is no evidence of any major climatic changes within the past 5,000 years (Cully 1977), there are indications of climatic variability (fig 6a).

The river has been a focus of human settlement and development since prehistoric times. This section addresses the hydrologic resource trends from about 5,000 years ago up to the present. Generally the MRG was a braided, slightly sinuous aggrading river with a shifting sand substrate. In the past, as now, the slope of the riverbed decreased from north to south and tributaries' contributions of water and sediment were important in defining the river's local and overall morphology.

Because there were no diversions and because of the relative hydrologic stability of the system, Crawford et al. believe that the Rio Grande generally supported perennial flows. Exceptions could have occurred during periods of prolonged drought and would have been more prevalent farther downstream. With no water regulation, the river's hydrograph would have reflected the seasonal events of snowmelt runoff and summer/fall precipitation (Fig. 6; note that these river discharge records do not reflect "natural" flows because upstream storage and diversions were already in place during the period of record, but they do indicate the general shape of the hydrograph).

The total flow in the MRG also fluctuated from year to year in response to annual climatic variability. Figure 6 graphs the total annual Rio Grande flows at the Otowi gauge above Cochiti over the past 100 years (fig. 6). Although these data also include the effects of human water management practices, they too are indicative of this annual variability. Figures 6a and 6b show temporal climatic variability and the effects of Cochiti Dam on the mean discharge respectively.

As human settlement and irrigated agriculture expanded in the middle valley and upstream in the upper Rio Grande Basin, more irrigation water was diverted from the river reducing total river discharges. The further downstream one proceeded in the system, the less water there was. Prior to the construction of storage and flood control facilities, diversions from the Rio Grande and some of its tributaries were limited to the growing season. Other seasonal flows, peak runoff, and precipitation flows were not affected. By 1913, storage reservoirs in the headwaters of the Rio Grande had been built, and in 1935 the MRGCD completed El Vado Reservoir on the Rio Chama (Shupe and Folk-Williams 1988). These facilities began to take peaks off of some of the high river discharges and to increase the duration of lower flows. The expansion of these reservoirs and the addition of the

flood and sediment control dams and reservoirs further accentuated this trend.

Other water management facilities have influenced the hydrology of the MRG. The 120 km (75 mi) long Low Flow Conveyance Channel, its downstream half operational in 1954 and its full length completed in 1959, reduced flows in the river channel in the Cicero Reach. The San Juan-Chama Project, completed in 1971, imports up to 110,000 acre-feet of San Juan River water from the Colorado River Basin to the Rio Chama/Rio Grande basins, 69,100 acre-feet of which is delivered to or through the middle valley. The effect of this importation has been to increase mean daily flows. In addition, the City of Albuquerque's annual treated wastewater discharge into the Rio Grande is currently about 60,000 acre-feet (R. Hogrefe, pers. comm in Crawford et al. 1993).

In all discussions regarding river morphology, it is important to recognize the differences within spatial and temporal scales. To describe a river system as being in a state of dynamic equilibrium (or energy balance) does not mean that it is static. To the contrary, this equilibrium results from a collection of processes that are by definition predicated on change. For example, even during periods when the entire river system is considered to be in a state of dynamic equilibrium, changes constantly occur in subareas as small as the outside band of a meander, or as large as many river kilometers upstream and downstream from a tributary inflow. Likewise, this state of dynamic equilibrium can accommodate climatic deviations from the norm distinguished between natural and human-caused perturbations. The geomorphic processes triggered in response to a change in magnitude or duration of a variable, regardless of the cause, will be the same (Leopold et al. 1964; The river constantly adjusts, always trying to establish a new equilibrium between its discharge and sediment load (Bullard and Wells 1992).

Prior to measurable human influence on the system, up to the 14th century (Biella and Chapman 1977), the river was a perennially flowing, aggrading river with a shifting sand substrate. As stated, its pattern was, as a rule, braided and slightly sinuous. The river would freely migrate across the floodplain, the extent being limited only by the valley terraces and bedrock outcroppings. The Rio Grande's bed would aggrade over time; then, in response to a hydrologic event or series of events, it would leave its elevated channel and establish a new course at a lower elevation in the valley. This process is called river avulsion (Leopold et al. 1964). Although an aggrading system, the Rio Grande was in a state of dynamic equilibrium, providing periods of stability that allowed riparian vegetation to become established on riverbends and islands alternating with periods of instability (e.g. extreme flooding) that provided, by erosion and deposition, new locations for riparian vegetation.

The earliest phase of significant water development activities (from about A.D. 1400 through the early part of this century) progressively decreased river flows as irrigated agriculture increased. More influential on the morphology of the river, however, was the increased sediment deposition into the ecosystem resulting from land-use activities in the watershed. When coupled with natural climatic variability, the net effect was to accelerate the raising (aggregation) of the riverbed and , accordingly, the frequency of overbank flooding and the river avulsion. The channel configuration, while still braided and sinuous, began to broaden and became shallower. Because the increasing rapidity of channel movement, riverbanks and islands were as a rule less stable. This likely contributed to an increased frequency of floods. Between 1822 and 1941, a total of 46 moderate floods was recorded along the reach (Crawford et al. 1993). During nonflood periods, diminished river flows caused the active channel to retreat to fewer, narrower channels within the wide and shallow sandy riverbed.

During the next phase of human interaction with the river, from the mid-1920's through 1950, a system of levees were constructed to constrain the river to a single floodway through portions of the middle valley. Concurrently, water diversions in the middle valley and upstream in the Rio Grande Basin increased. This had the net effect of further accelerating channel aggradation, especially in those areas where levees concentrated the deposition of sediment in the floodway.

In the contemporary phase of human water management beginning in the early 1950's, the sediment and flood control structures constructed in the upper portion of the MRG valley accelerated the reversal of channel aggradation in the Cochiti

and Albuquerque reaches. The lowering riverbed is resulting in a more incised and sinuous single-channel river (see Fig. 7 for a visual example in the Belen Reach). This process becomes less pronounced with downstream distance from Cochiti and Jemez Dams. With reduction of the peak flows, where unregulated tributaries and arroyos such as Calabicillas Arroyo discharge into the Rio Grande, adequate flows are not available to transport the sediment. Sediment deltas are more persistent; they reduce river gradient upstream (tending to increase aggradation) and increase the gradient downstream (tending to reduce aggradation).

The channel modification process, described above, immediately affected the river's channel morphology. To increase the water delivery efficiency and flood flow capacity within the floodway the BOR initiated a river channel maintenance program in 1953. This included Bank stabilization, river training, sediment removal, and vegetation control. Although the techniques have evolved over the years, the program continues. Within the

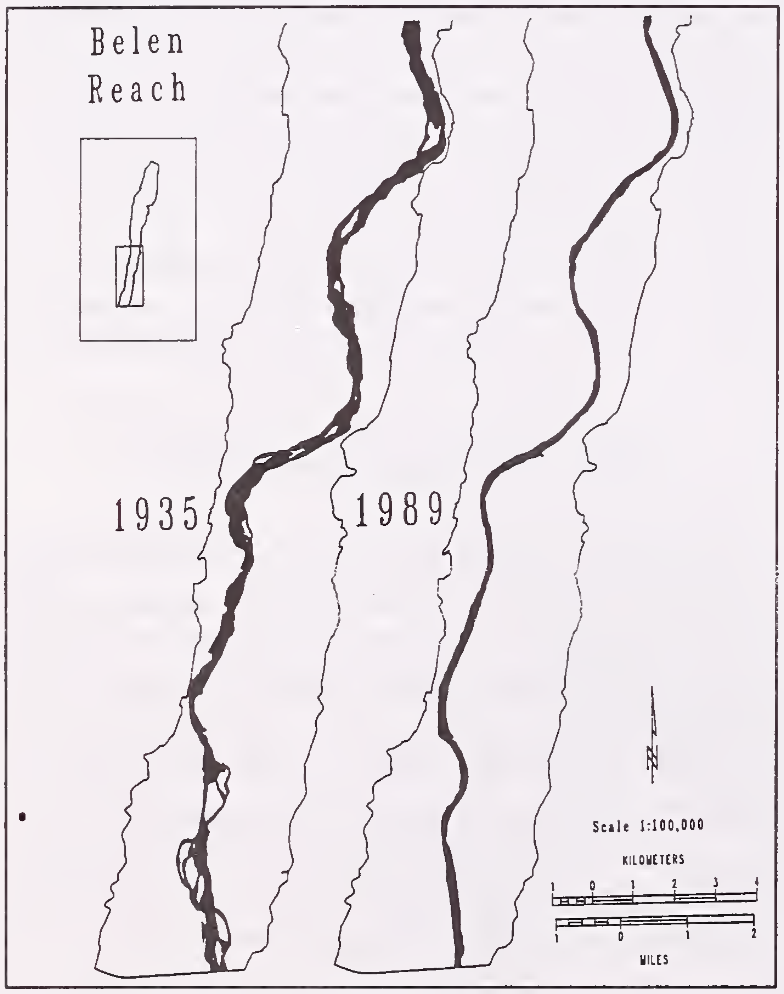


Figure 7. Changes from braided to single channel, 1935-89, portions of Belen Reach, Middle Rio Grande (from Crawford et al., 1993).

stabilized floodway, reaches of the MRG have been straightened, the irregularity of the channel width has been reduced, and the riverbanks have been stabilized.

INSTITUTIONAL INFRASTRUCTURE

The waters of the Rio Grande are managed by an interwoven fabric of federal, state, interstate, and international water laws, agreements, and regulations. The fabric defines how water is released through the system, influencing not only the quantity of water, but often the timing of the releases as well. The following are the principal management components.

THE TREATY OF 1906 - Provides for the annual delivery of 60,000 ac/ft to Mexico. Prompted by the Reclamation Act of 1902 and the resulting study identifying construction of Elephant Butte Dam which was authorized in 1905 and completed in 1916.

THE RIO GRANDE COMPACT - Initiated in 1923 and agreed upon in 1929, approved by Congress in 1939, allocates Rio Grande water between the states of Colorado, New Mexico, and Texas via a complex set of delivery schedules that relate runoff volumes to delivery obligations at set river index points. In normal years New Mexico must assure delivery of 60% of the flow passing Otowi gage reaches Elephant Butte Reservoir which is the delivery point for Texas' allocation. In wet years the percentage is 80%. The Compact also provides rules for accruing and repaying water credits and debits, water storage restrictions, and operation of reservoirs. The compact does not affect obligations to Mexico or to Indian tribes (Shupe and Folk-Williams 1988).

MIDDLE RIO GRANDE CONSERVANCY ACT 1923 - Formed the Middle Rio Grande Conservancy District in 1925 in response to decrease in productive, irrigated farmland and increased flooding along the MRG. Channel Aggradation, flooding, and waterlogging of arable lands resulted from Rio Grande water infiltrating the groundwater system of the lower, surrounding floodplains. This resulted in a dramatic decrease in productive farmland from 50,000 ha to 16,000 ha by 1925 (Nanninga 1982). From 1925 to 1935 the MRGCD constructed, operated, and maintained four major diversions dams (Cochiti, Angostura,

Isleta, and San Acacia), two canal headings, and many miles of drainage canals, river levees, and main irrigation canals (fig 8). Initial flood control structures were 2.5 m spoil levees that paralleled the Rio with a mean channel width of 450 m. From 1951 to 1977 a system of Kellner jetty fields was installed along the MRG to protect levees and to aid in flood control and channel stabilization.

In recognition of continued flooding and sedimentation problems on the MRG, the COE and BOR jointly prepared the "Rio Grande Comprehensive Plan". The COE's portion of the plan provided Jemez Canyon Dam in 1953, Abiquiu Dam and Reservoir in 1963, Galisteo Dam in 1970, and Cochiti Dam and Reservoir in 1973. The system consisting of Abiquiu, Jemez Canyon, Galisteo, and Cochiti dams and the levees along the Rio Grande provides flood control and protection for the MRG valley (Lagasse 1980).

El Vado Reservoir on the Rio Chama was proposed by the MRGCD in 1928, providing irrigation water and flood control to the MRG. Under an agreement with the Department of Interior, El Vado also provided irrigation water to the 6 Indian pueblos in the area (Cochiti, Isleta, San Felipe, Santa Ana, and Santo Domingo). The dam was completed in 1935 and rehabilitated in 1958. Operating responsibility was transferred to BOR in 1956.

FLOOD CONTROL, DIVERSION PROJECTS, AND PUBLIC LAWS

CABALLO DAM, located 27 km below Elephant Butte Dam, was authorized in 1933. This provides flood control for El Paso and the Juarez Valley. It is managed by both the BOR (conservation operations), and the International Boundary and Water Commission (IBWC) (flood control).

PLATORO DAM AND RESERVOIR, on the Conejos River in Colorado, was authorized in 1940 for conservation and flood control and completed in 1951.

FLOOD CONTROL ACT OF 1948 authorized construction of Jemez Canyon Reservoir and the low-flow conveyance channel from San Acacia to Elephant Butte Reservoir. It also authorized the

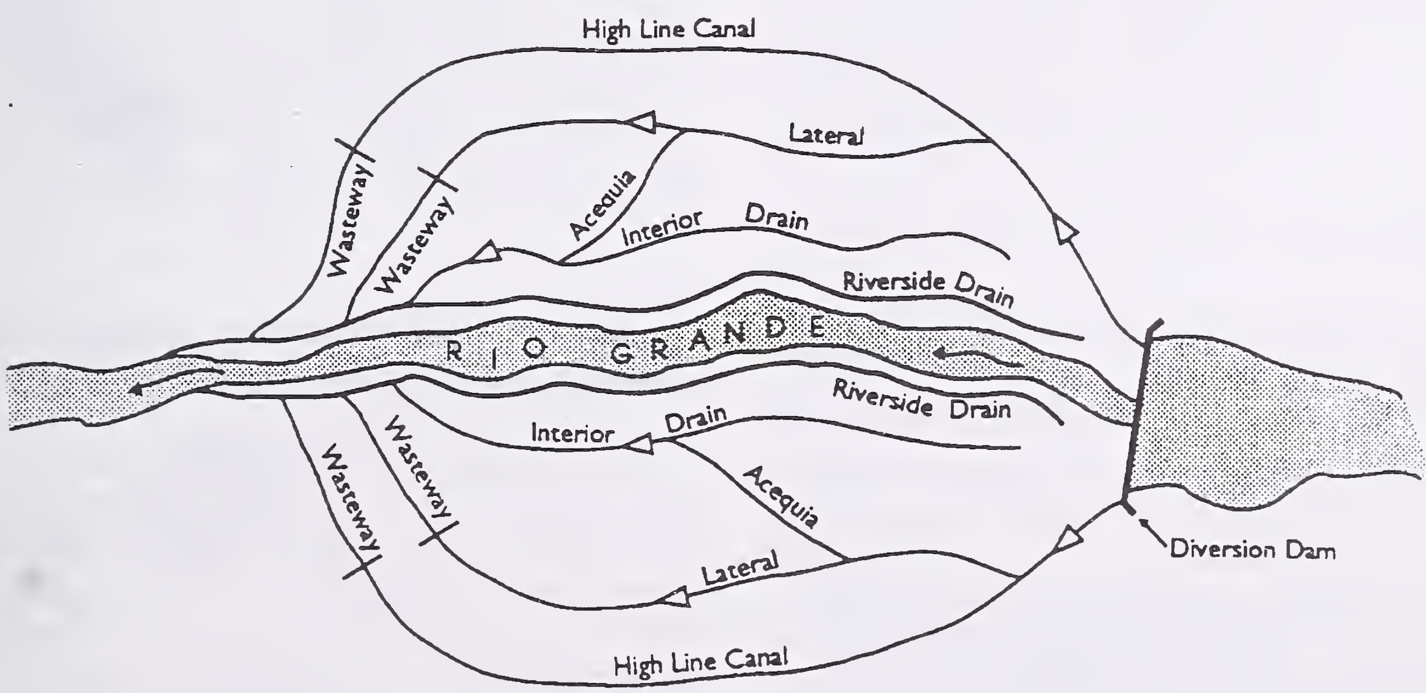


Figure 8. Schematic map of an irrigation network on the Middle Rio Grande (Bullard and Wells, 1992).

BOR to maintain the Channel of the Rio Grande from Velarde to Caballo Reservoir to accommodate flows of about 5,000 CFS.

The Low Flow Conveyance Channel is used to transfer water through its 82 km length more efficiently during periods of low flow, which minimizes water losses to infiltration and phreatophytes. The low-flow conveyance channel is normally operated to convey the entire flow in the Rio Grande up to about 2,000 cfs; when flows exceed about 2,000 cfs, the remainder is carried by the natural channel. Water is also allowed to flow in the natural channel when the silt load is high.

FLOOD CONTROL ACT OF 1960 - The Flood Control Act of 14 July 1960 (PL48-645) contains the criteria governing operations of the four Middle Rio Grande Project flood control reservoirs: Jemez Canyon, Abiquiu, Cochiti, and Galisteo. Portions of the operating criteria include:

- The reservoirs are operated only for flood control.
- Cochiti spring outflow will be at the maximum rate of flow without causing flooding of leveed protected areas.
- Provided there is at least 212,000 ac ft of storage available for regulation of summer floods and inflow is less than 1500 cfs, no water will be withdrawn from storage in Cochiti Reservoir.
- Jemez and Galisteo will be managed during July through October to only handle summer floods.
- All Reservoirs will be evacuated by March 31, each year.
- When it benefits Colorado or New Mexico in Compact, deliveries of a flow of 10,000 cfs is authorized through the Albuquerque reach.
- No departure from the foregoing schedule is allowed without consent of the Rio Grande Compact Commission.
- In the event of an emergency, the COE must advise the Compact Commission in writing, and the foregoing rules of operation may be suspended during the period of emergency.

SAN JUAN-CHAMA TRANSMOUNTAIN DIVERSION PROJECT - 1963 - The SJC Project imports water from the San Juan River basin (in the Colorado River basin). This water is not subject to Rio Grande Compact, and can thus be used for beneficial use (COE 1989). Annual diversion of about 110,000 ac ft is authorized. The imported water is stored and released at Heron Reservoir. This water is allowed to be used for municipal, irrigation, domestic, and industrial purposes, and to provide recreation and fish and wildlife benefits.

ALBUQUERQUE METROPOLITAN ARROYO FLOOD CONTROL AUTHORITY (AMAFCA) - Following several large, damaging floods east of the Rio Grande in urban Albuquerque in 1955, 1961, and 1963 AMAFCA was created in 1963 to address and alleviate the problems of urban flooding from unregulated ephemeral tributaries. A series of concrete lined drainage structures were constructed from arroyos at the foot of the Sandia Mountains and feed into the Rio Grande.

THE CLOSED BASIN PROJECT - The Closed Basin Project in Colorado was authorized by PL 92-514 in 1972. The purpose is to help Colorado meet its required deliveries to New Mexico, and to help all three Rio Grande Compact States meet their delivery requirement to Mexico. The closed basin Project was justified and funded 100% by the federal government on the basis of honoring the Treaty of 1906. The project consists of 170 salvage wells that remove groundwater from the unconfined aquifer in the Closed Basin and discharge the water into the Rio Grande. The water would normally be consumed by evapotranspiration. Approximately 60,000 to 140,000 ac ft of water is delivered to the Rio Grande at rates up to 140 cfs when fully operational.

CURRENT HYDROLOGIC REGIME AND ITS EFFECTS ON THE RIPARIAN VEGETATION

Present conditions in the Rio Grande include levees, dams, and channelization. Cochiti Dam has had a major impact on the river and riparian zone below it by reducing peak flows and sediments in the system (fig. 6b). The timing and duration of releases of peak flows may not be suitable for germination and establishment of native species (Fenner et al. 1985, Szaro 1989). In contrast to unmodified riverine systems (fig. 9), levees have restricted the lateral movement of the river, and channelization has occurred along some reaches

(fig. 10). The consequence of all these actions for native riparian vegetation, once areas have become vegetated, is a drastic reduction in numbers of sites and opportunities for further recruitment.

Probably as a result of the construction of Cochiti Dam, the northern reaches (Cochiti and Albuquerque) of the Middle Rio Grande are now degrading. Because sediments are trapped at the dam, released waters have high potential for erosion and the channel is deepening. Vegetation is stabilizing the riverbanks, enhancing the narrowing and deepening of the channel. Comparison of 1935 and 1989 aerial photos indicates that the riverine, or river channel portion of the MRG , has been reduced by 49%(8,920 ha [22,032 ac] in 1935 to 4,347 ha [10,736 ac] in 1989 (fig. 7). For native riparian plant species, there is little or no recruitment, except for banks and bars adjacent to the main channel of the river that are exposed after high flows. These areas may be scoured by the next high flows and are often subject to mowing to maintain the floodway. This lack of recruitment is a consequence of the presence of existing riparian vegetation and the absence of high magnitude flows to remove established vegetation and create barren areas for colonization.

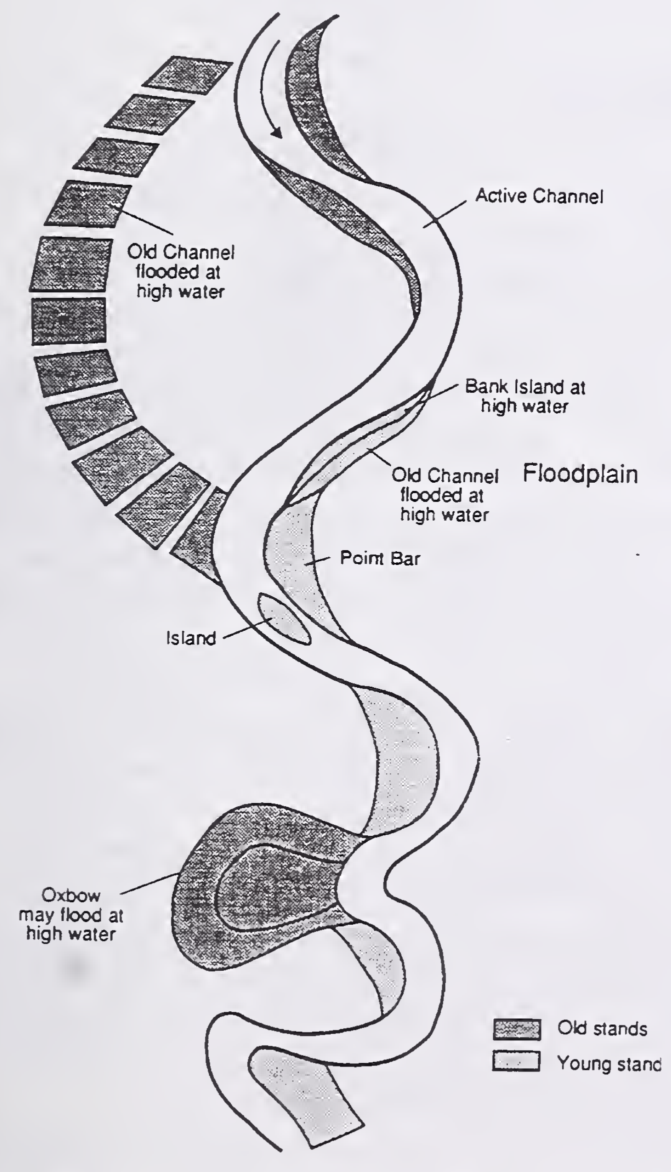


Figure 9. Zones of cottonwood and other riparian species establishment along an unmodified river (Crawford et al, 1993).

In the southern reaches (Belen and Socorro) of the MRG, large amounts of sediment are introduced into the system at the confluence of the Rio Puerco and Rio Salado (Lagasse 1980). Some areas are without levees, and waters spread out here and deposit sediments. In these reaches, decreases in peak flows prevent sediments in the channel from being moved downstream. At the southern end of the MRG, Elephant Butte Dam has caused the base elevation to rise upstream enhancing deposition, channel widening, river braiding, and aggrading in some areas. Sediment deposition creates substrate for recruitment of native cottonwoods and willows and introduced salt cedar.

Much of the riparian zone along the MRG is dominated by cottonwood trees, which form a sparse to dense canopy cover along the river. In the understory, native species include the shrub coyote willow, seepwillow, false indigo bush, New Mexico olive, and others. Introduced species have become increasingly important in numbers, frequently becoming dominant species in the understory and occasionally in the canopy. In the northern reach, the major introduced species in Russian olive. In the south (below Bernardo), salt cedar is prevalent in the understory, and it also forms large monotypic stands along the river and adjacent floodplain. Other introduced species (e.g. Siberian elm, tree-of-heaven, china-berry tree, mulberry, and black locust) are found in the bosque, mostly along levee roads and in other disturbed communities now dominated by native species. These exotics have the potential for becoming the primary species there through time.

Six structural types of plant communities were recognized by Hink and Ohmart (1984) (fig.11), based on the overall height of the vegetation and the amount of vegetation in the understory or lower layers. Type I had vegetation in all layers, with trees 15-18 m ((50-60 ft) high. Type I areas were mostly mixed to mature age class stands dominated by cottonwood/coyote willow, cotton-

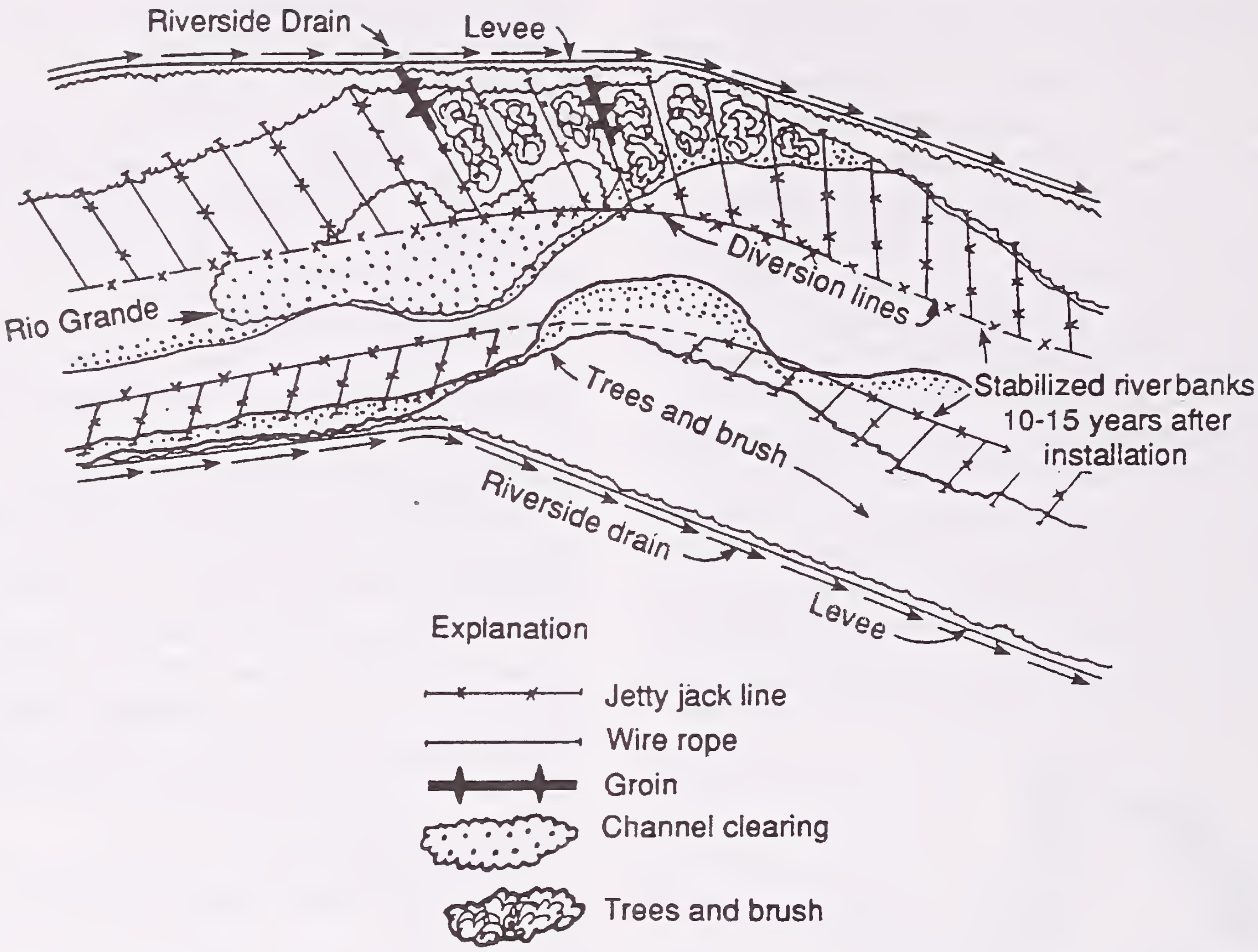


Figure 10. Channel stabilization works on the Middle Rio Grande (after Bullard and Wells, 1992).

wood/Russian olive, and cottonwood/juniper. Type II areas consisted of mature trees from 15 to 18 m (50-6- ft) with a sparse understory. Intermediate age stands of cottonwood trees with a dense understory were classified as Type II, while similarly aged trees with open understory were called Type IV. Type V was characterized by dense vegetation up to about 4.6 m (15 ft) often with dense grasses and annuals. Type VI had low, often sparse vegetation, typical of sandbars with cottonwood, willow, and other seedlings. This type also included sparsely vegetated drains.

Hink and Ohmart (1984), described three cottonwood-dominated community types based on the overstory species and on the type and abundance of the understory species. The cottonwood/coyote willow community, cottonwood/Russian olive, and cottonwood/juniper found in the northern reach. New Mexico olive, false indigo bush and other species were also found.

Other plant communities also occurred in the study area (Hink and Ohmart 1984). Russian olive occurred along the river channel in narrow, 15-60 m (50-200 ft wide bands. Cattail marshes, dominated by cattails with some bulrush and sedge, are found in areas that are inundated or have a high water table. Wet meadows with saltgrass and sedges were also designated as marsh communities. In the southern reach, salt cedar was the primary component of the plant community almost to the complete exclusion of other species.

Hink and Ohmart (1984) also delineated sandbars in and adjacent to the river, and the river channel. Most of the sandbars were bare, but some had developed vegetation consisting of grasses, forbs, cottonwood and willow seedlings, and other species. Many of these bars were scoured during each year's high flows. If not removed by scouring, vegetation in these locations is periodically mowed by the BOR to keep the floodway clear.

While the structure and diversity of native plant communities appear to be significant to the diversity of species in animal communities, introduced plant species that have become naturalized in the

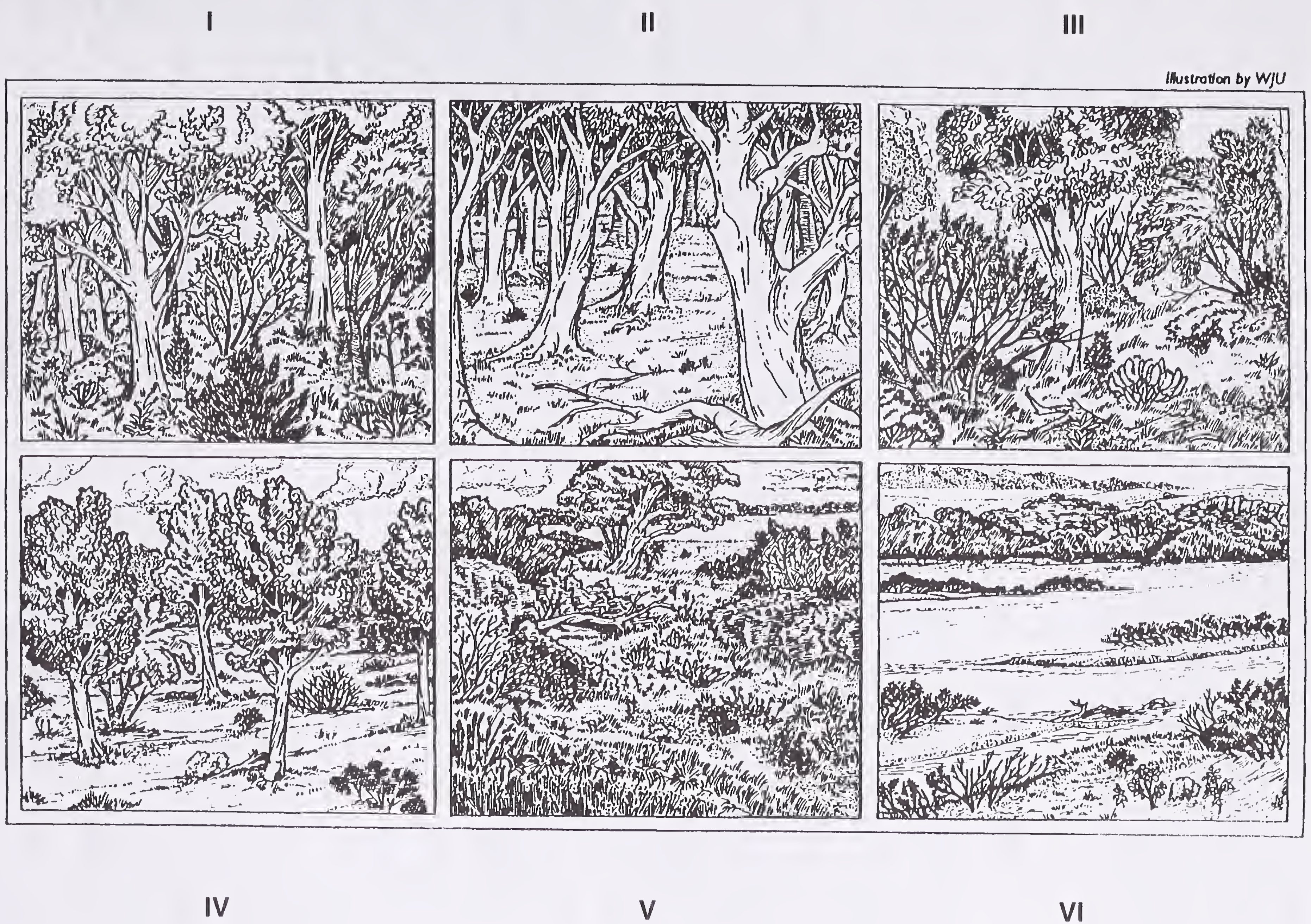


Figure 11. Vegetation structural types I-VI, Middle Rio Grande riparian zone (after Hink and Ohmart, 1984).

region also provide shelter and sometimes food. The fruits of the Russian olive, a species which is prominent in the community types in the northern reach of the MRG, appear to be a significant part of the diet for some resident, migrant, and breeding bird species. Salt cedar found throughout the study area but particularly abundant in the southern portion, provides cover for birds and mammals and habitat for many insect species (Hink and Ohmart 1984).

CONCLUSION

The MRG has been the center of considerable activity by man for over 10,000 years. Until only recently man's activities have not had a significant impact on the character of the riparian area adjacent to the Rio Grande in this vicinity. With advent of irrigation, control structures such as levees and Jetty Jacks, water diversions and control structures such as Cochiti Dam, the hydrograph and subsequent river morphology have been dramatically altered. This alteration in flow regimes and channel configuration continues to have ramifications and effects upon the native flora and fauna of the MRG.

ACKNOWLEDGMENTS

Much of what is contained in this paper comes directly from primarily two documents which I highly recommend to the reader. The first "Hydrology of the Middle Rio Grande from Velarde to Elephant Butte Reservoir, New Mexico" by Bullard and Wells 1992. The second indispensable document is the Middle Rio Grande Bosque Biological Management Plan, Crawford et al. 1993. The Figures have been taken from the Bosque Biological Management Plan, Crawford et al. 1993.

LITERATURE CITED

Allen, C., B. Hanson, and C. Mullins (eds.). 1993. Cochiti Reservoir reregulation interagency biological report. Report submitted to Rio Grande Joint Initiatives Committee, National Park Service, Bandolier National Monument, Los Alamos, New Mexico.

Biella, J.V., and R.C. Chapman (eds.) 1977. Archeological investigations in Cochiti Reservoir, New Mexico. Volume 1: a survey of regional variability. Report submitted to national Pard Survey, Santa Fe, for U.S. Army Corps of Engineers, Albuquerque.

Brandvold, D.K., C. J. Popp, T.R. Lynch, and L.A. Brandvold. 1984. Heavy metals and pesticides in water, sediments, and biota in the Middle Rio Grande Valley. Pages 14-23 in W.J. Stone, compiler. Selected papers on water quality and pollution in New Mexico. New Mexico Bureau of Mines and Mineral Resources, Hydrological Report 7.

Brown, D.E. and C.H. Lowe. 1980. Biotic communities of the Southwest. U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report RM-78.

Bullard, T.F. and S.G. Wells. 1992 Hydrology of the Middle Rio Grande from Velarde to Elephant Butte Reservoir, New Mexico. U.S. Fish and Wildlife Service, Resource Publication 179.

Crawford, C.S., A.C. Cully, R. Leutheuser, M.S. Sifuentes, L.H. White, J.P. Wilber. 1993 Middle Rio Grande Ecosystem: Bosque Biological Management Plan.

Cully, A.C. 1977. Paleoclimatic variability in the North-Middle Rio Grande, New Mexico. Pp. 97-101 in J.V. Biella and R.C. Chapman (eds.) Archeological investigations in Cochiti Reservoir, New . Volume 1; a survey of regional variability,. Report submitted to National Park Survey, Santa Fe, for U.S. Army Corps of Engineers, Albuquerque.

Fenner, P., W.W. Brady, and D.P. Patton. 1985. Effects of regulated water flows on regeneration of Fremont Cottonwood. Journal of Range Management 38:135-138.

Hawley, J.W., compiler. 1978. Guidebook to Rio Grande Rift in New Mexico and Colorado. New Mexico Bureau of Mines and Mineral Resources, Circular 163. 241 pp.

Heath, D.L. 1983. Flood and recharge relationships of the Lower Rio Puerco, New Mexico. Pp. 329-337 in New Mexico Geological society Guidebook, 34 Field conference, Socorro Region II. Socorro, New Mexico.

Hink, V.C. and R.D. Ohmart. 1984. Middle Rio Grande biological survey. Report submitted to U.S. Army corps of Engineers, Albuquerque, New Mexico.

Hunt, C.B. 1974. Natural region of the Untied States and Canada. W.H. Freeman & Co., San Francisco, Calif. 725. pp.

Kelson, K.I. 1986. Long-term tributary adjustments to base-level lowering, northern Rio Grande Rift, New Mexico. M.S. thesis, University of New Mexico,
Albuquerque. 210 pp.

Lagasse, P.F. 1980. An assessment of the response of the Rio Grande to dam construction-Cochiti to Isleta Reach. Technical Report submitted to U.S. Army Corps of Engineers, Albuquerque, New Mexico.

Leopold, L.B., M.G. Woldman, and J.P. Miller. 1964. Fluvial processes in geomorphology. W.H. Freeman and Co., San Francisco.

Lozinski, R.P., J.Hawley, and D. Lowe. 1991. Geologic overview and Pliocene-Quaternary history of the Albuquerque Basin, New Mexico. Pp 157-162 in B. Julian and J. Zidek (eds.) Field guide to geologic excursions in New Mexico and adjacent areas of Texas and Colorado Bulletin 137. New Mexico Bureau of Mines and Mineral Resources, Socorro.

Maker, H.J., J.M. Downs, and J.U. Anderson. 1972. Soil associations and land classification for irrigation, Sierra County. New Mexico State University Agricultural Experiment Research Station Report 233.

Nanninga, R.S. 1982. Middle Rio Grande valley prior to the advent of the conservancy district. Pages 99-101 in J.A. Grambling and S.G. Wells, editors. Albuquerque Country II. New Mexico Geological Society Guidebook 33.

Ouchi, S. 1983. Effects of uplift on the Rio Grande over the Socorro magma body, New Mexico. Pages 54-56 in C.E. F. Chapin, editor. Socorro Region II. New Mexico Geological Society Guidebook 34.

Ouchi, S. 1985. Response of alluvial rivers to slow active tectonic movement. Geological Society of America Bulletin 96:504-515.

Popp, C.J., D.K. Brandvold, T.R. Lynch, and L.A. Brandvold. 1983. An evaluation of sediments in the Middle Rio Grande, Elephant Butte Reservoir and Caballo Reservoir, as potential sources for toxic materials. New Mexico Water Resources Institute WRRI Report 161.97 pp.

Richards, K. 1982. Rivers: Form and process in alluvial channels. Methuen, London. 358 pp.

Schumm, S.A. 1977. The Fluvial System. John Wiley and Sons, New York.

Schumm, S.A. 1986. Alluvial river response to active tectonics. Pages 80-94 in Active tectonics; studies in geophysics. National Research Council. National Academy Press, Washington, D. 266 pp.

Shupe, S.J., and J. Folk-Williams. 1988 The Upper Rio Grande: a guide to decision-making. Western Network, Santa Fe, New Mexico.

Szaro, R.C. 1989. Riparian and forest and scrubland community types of Arizona and New Mexico. Desert Plants 9:70-135.

Tuan, Y-F., C.E. Everard, and J.G. Widdison. 1973. The climate of New Mexico. State Planning Office, Santa Fe, New Mexico.

U.S. Army Corps of Engineers. 1979. Albuquerque greater urban area, urban studies program, water supply, Appendix III. U.S. Army Corps of Engineers, Albuquerque District.

U.S. Army Corps of Engineers. 1989. Reevaluation of the Rio Grande operating plan. Albuquerque District Office.

U.S. Bureau of Reclamation. 1981. Project data. U.S. Government Printing Office, Washington, D.C. 1463 pp.

Wells, S.G., K.I. Kellson, and C.M. Menges. 1987. Quaternary evolution of fluvial systems in the northern Rio Grande Rift, New Mexico and Colorado: implications for entrenchment and integration of drainage systems. Pages 55-69 in C. Menges, editor. Quaternary tectonics, landform evolution, soil chronologies and glacial deposits-northern Rio Grande Rift of New Mexico. Friends of the Pleistocene-Rocky Mountain Cell Field Trip Guidebook.

Wozniak, F.E. 1987. Irrigation in the Rio Grande Valley, New Mexico: a study of the development of irrigation systems before 1945. The New Mexico Historic Preservation Division, Santa Fe, and U.S. Bureau of Reclamation, Southwest Regional Office, Amarillo, Tex. Contract BOR-87-1. 191 pp.

Riverine settlement in the evolution of prehistoric land-use systems in the Middle Rio Grande Valley, New Mexico

Joseph A. Tainter[1] and Bonnie Bagley Tainter[2]

Abstract.—Ecosystem management should be based on the fullest possible knowledge of ecological structures and processes. In prehistoric North America, the involvement of Indian populations in ecosystem processes ranged from inadvertent alteration of the distribution and abundance of species to large-scale management of landscapes. The knowledge needed to manage ecosystems today is incomplete without understanding past human involvement in ecological processes, and the adjustments of ecosystems to human components. This paper describes changes in prehistoric land use in part of the Middle Rio Grande Valley, New Mexico. Processes of economic change, land-use intensification, and regional abandonment suggest that there were periods of significant prehistoric disturbance to both upland and valley ecosystems.

INTRODUCTION: HISTORICAL SCIENCE IN ECOSYSTEM RESEARCH

One advantage of the growing role of social scientists in Forest Service research is the opportunity for both social and biophysical scientists to offer fresh perspectives on each other's assumptions and approaches. Every scientist and every manager works with a set of professional assumptions that, on a daily basis, usually remains implicit. To a scientist from another field these assumptions can take on fresh meanings, and perhaps yield different perspectives.

An emerging research topic that promises fruitful collaboration between social and biophysical scientists is understanding the human role in the evolution of North American ecosystems. The early notion of North American Indians as low-density dwellers in a primordial garden is giving way to a more realistic view. The prehistoric occupants of this continent lived at times in dense, concentrated populations. In some places they modified landscapes to increase production of the resources that they needed. In other places they manipulated vegetation to select for early seral stages and to increase the abundance of particular prey species (Lewis 1973; Cronon 1983; Kay 1995; Sullivan 1995). It is no longer possible to think of North America as a pristine wilderness at the time of European contact. It now seems clear that what Europeans encountered in this continent were ecosystems that had been changing for millennia along with, and in response to, American Indian populations that grew many times in size and density, and whose societies came to be increasingly complex and to require higher and higher levels of resources (e.g., Tainter 1988: 178-187; 1995).

Viewing the prehistory of North American ecosystems in this way leads to significant questions about environmental conditions today. At a fairly obvious level it leads one to ask what is

[1] Research Archaeologist, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station and Project Leader, Cultural Heritage Research Work Unit, located in Albuquerque, NM.

[2] Archaeologist, editor, and independent consultant; P.O. Box 145, Corrales, NM 87048.

meant by terms such as *reference conditions, restoration*, or *range of natural (or historic) variation* (e.g., Wright, Chapman, and Jimerson 1995), and whether these terms are thought to apply to ecosystems without human involvement. At a more subtle level, if ecosystem management involves managing with a knowledge of the structures and processes of ecosystems, that knowledge must remain significantly incomplete without an understanding of the past human role in ecosystem processes. Indeed, one might assert that we lack much fundamental knowledge of how North American ecosystems functioned before A.D. 1500 (cf. Cartledge and Propper 1993). If we are to understand reference conditions, we need to know how ecosystems have functioned with human components that ranged from low-density foragers to high-intensity occupations by people who deliberately manipulated their environments, and who retained and transmitted environmental knowledge through myth, ritual, and oral traditions (cf. Gunn 1994).

Although we can pose such queries, we cannot yet say definitively what their implications are. Though we know that American Indians in prehistory were integral parts of ecosystems, the investigation of cultural-ecological processes in the past is only coming to be recognized as important. In this paper we will discuss the prehistory of an area that witnessed dramatic transformations in the patterns of its human occupation over a period of more than 7,000 years. The patterns of this occupation have important implications for the evolution of local ecosystems, including disturbance processes.

PREHISTORIC LAND USE IN THE MIDDLE RIO GRANDE VALLEY

The area of this study extends from the Rio Grande Valley on the east to the Rio Puerco on the west, and from about the confluence of the Rio Jemez and the Rio Grande on the north to just south of Albuquerque on the south (fig. 1). Lying between the Rio Grande and Rio Puerco basins is a broad, eroded tableland known colloquially as the West Mesa (and called more properly the *Llano de*

Figure 1. The Middle Rio Grande study area.

Albuquerque). It is a low feature, rising no more than about 225 m. above the floodplains. The Albuquerque West Mesa is a desert grassland containing riverine gravels and erosional remnants of the ancestral Rio Grande. It is devoid of flowing surface water, and the 19th century historian and explorer Adolph Bandelier even described it as "...waterless, bleak, and bare" (1892: 309).

To Euro-Americans, the most desirable landscapes within this area are the fertile river valleys. These are where Hispanic and Anglo-American farmers settled first. It is therefore surprising to learn that in perhaps 12,000 years of occupation by American Indians, the Rio Grande and Rio Puerco valleys are where aboriginal populations came to settle *last*. The early Native American use of this region appears actually to have clustered in precisely those areas that, in a Euro-American view, are most marginal. This apparent paradox illustrates the inherent variability in cultural perceptions of landscapes, and the flexibility of human involvement in landscape processes.

The long time span from about 5500 B.C. to 0 A.D. is called by archaeologists the Archaic period. The mode of subsistence throughout this time was hunting and gathering. Some time in the last millennium B.C. small amounts of maize were added to the diet, but people did not come to depend on agriculture until after about 500 A.D. (Glassow 1972; Hegmon 1995). It is in the context of a hunting and gathering economy that we can understand the early prehistoric landscape preferences.

The hunting and gathering populations of the Archaic period appear to have concentrated initially for at least part of the year on the upper reaches of the Arroyo Cuervo, which is a tributary of the Rio Puerco (fig. 2). Among the reasons for choosing this area are the occurrence of very reliable sources of water in the form of seeps at the heads of side canyons (Irwin-Williams 1973), and the fact that the Arroyo Cuervo has some of the highest topographic diversity in the region.

The topographic diversity in particular helps to explain why early foragers preferred this area to

Figure 2. Archaic site distribution, ca. 5500 B.C.-0 A.D.

the river valleys. At the end of the Pleistocene, vegetation zones were lower in elevation than they are today. The West Mesa would have supported a ponderosa pine forest, with spruce and fir on the highest ridges (Judge 1973: 40). With the drying and warming of succeeding millennia, vegetation zones migrated higher in elevation and northward, and the Pleistocene megafauna became extinct. The economy established locally in response to these changes is generally considered to have been a mixture of hunting prey species such as deer, antelope, and rabbits, and gathering plant foods such as grass seeds, forbs, succulent seeds and fruits, early season greens, and pinyon nuts. Such resources are widely but discontinuously distributed throughout the Upper Sonoran life zone, which today encompasses all of the study area.

For a hunting and gathering population in an arid region, survival depends on mobility. As edible plants ripen at different locations throughout the year, a population of human consumers must continuously reposition themselves on the landscape. Transportation of food by people typically has a high energetic cost (Lightfoot 1979). Food transported as little as 100 km. may cost as much as 1/3 of its energy value in consumption by human bearers (Culbert 1988: 93). It is generally necessary, therefore, for hunter-gatherers to move consumers to resources rather than resources to consumers. The entire population must be mobile. A yearly seasonal round for Southwestern foragers might have started with a move to lower elevations for early spring greens, movement throughout mid elevational ranges from late spring through early fall to take advantage of seed-bearing plants and succulent fruits, then to higher elevations in the fall to gather pinyon nuts and engage in late-season hunting of ungulates. If the pinyon crop was particularly good, winter occupation would have had to be near where the nuts were gathered and stored.

Topographic diversity can ameliorate the need for high mobility. In a landscape with significant altitudinal variation, a variety of edible plant foods becomes available throughout the year. These are

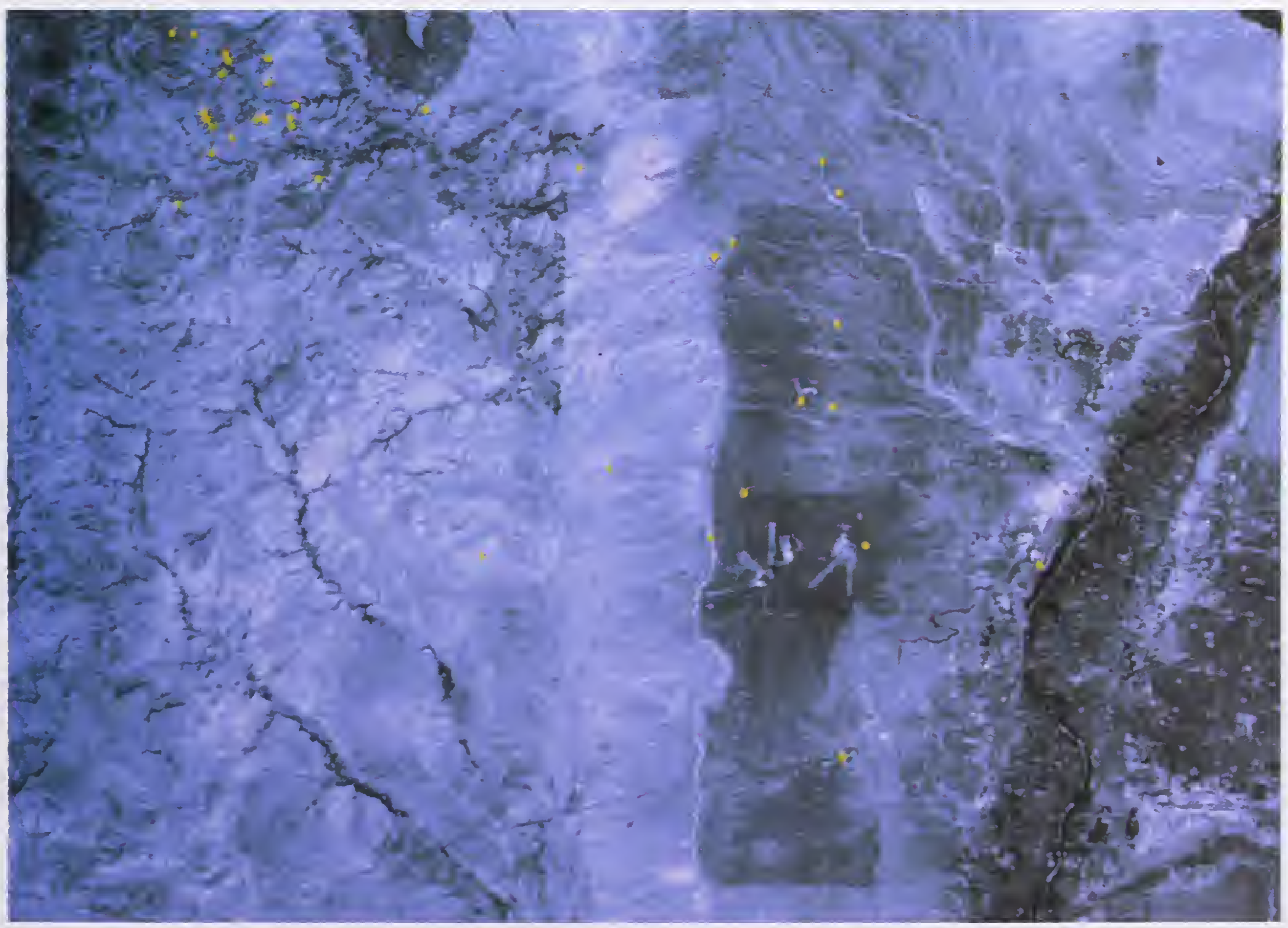


Figure 3. Basketmaker II site distribution, ca. 0-500 A.D.

separated by large vertical distances but small horizontal distances. A topographically diverse landscape allows hunters and gatherers to obtain a yearly round of resources with less mobility than would otherwise be necessary (Tainter and Gillio 1980: 17). In a landscape that is highly diverse, a foraging population might even be able to become sedentary, and exploit a full range of resources from a single location. The topographic diversity of the Arroyo Cuervo region does much to explain why the Archaic-period American Indian populations preferred to settle in an area that Euro-Americans consider useful for little more than cattle raising.

The main investigator of the archaeological sites in the Arroyo Cuervo region, the late Cynthia Irwin-Williams, found evidence of population growth in the prehistory of the area, particularly after about 3,000 B.C. (Irwin-Williams 1973). Although the population of hunter-gatherers probably never exceeded an average of one person per one or two square kilometers, in time this growing population led to predictable consequences. From about 3,000 to 2,000 B.C. onward there was increasingly intensive use of the West Mesa (Reinhart 1967; Campbell and Ellis 1952; Tainter and Gillio 1980: 46-48), where people built structures, probably of stone, brush, and hides, for short-term occupation (Deni Seymour, personal communication, 1995). In the Arroyo Cuervo region stones for breaking and grinding seeds and nuts were added to the technology, suggesting that these foods played an increasingly important part in the diet.

After about 2,000 B.C. the pace of change quickened. Larger social groups formed at the Arroyo Cuervo canyon heads (Irwin-Williams 1973: 11), and there may have been greater social integration through ritual. By the end of the last millennium B.C. the residents of the West Mesa were occupying sand dune-covered ridges overlooking drainages, and building more substantial subterranean structures (Reinhart 1967).

In the first few centuries A.D. continued growth of population made the hunting and gathering

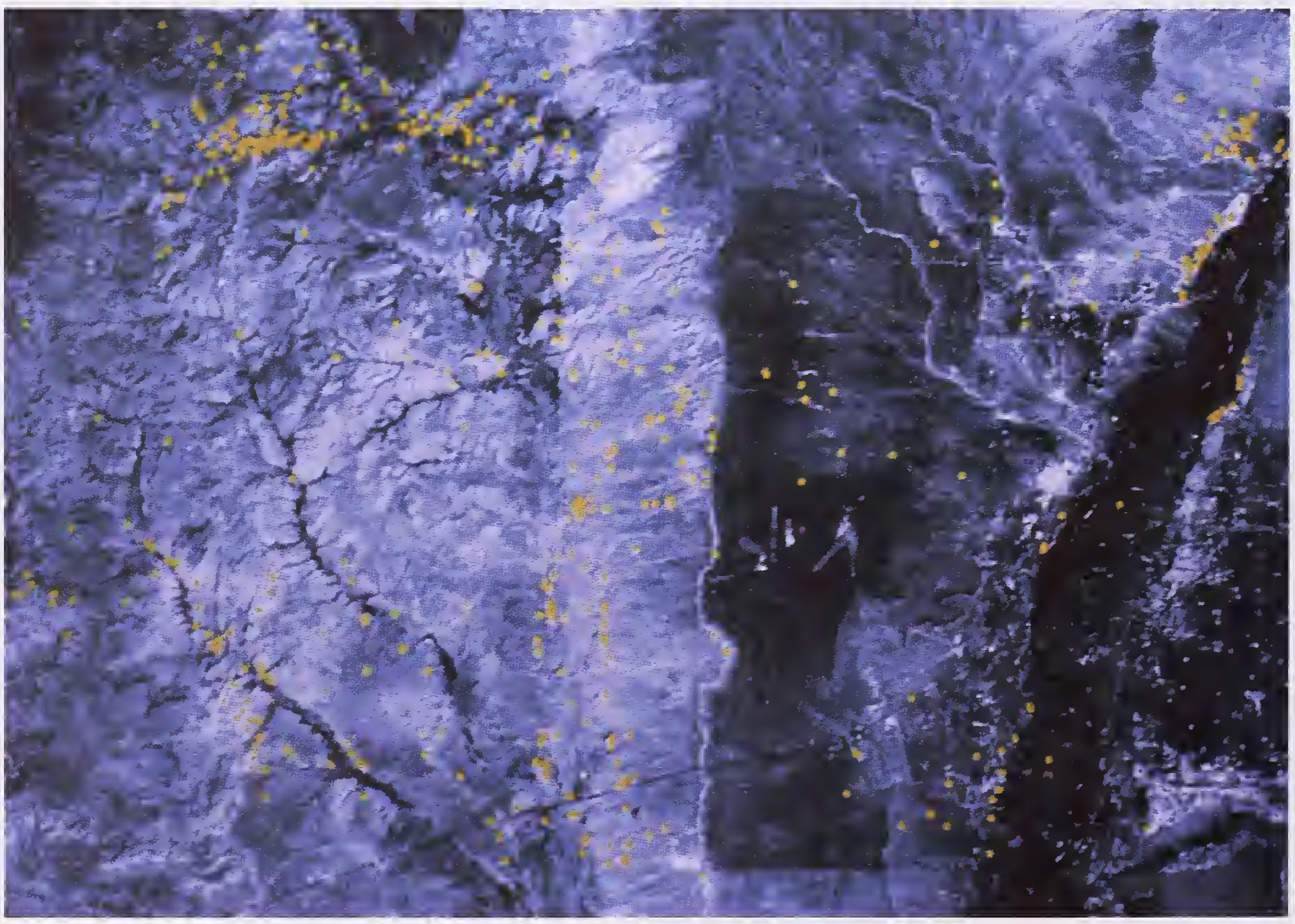


Figure 4. Basketmaker III-Pueblo II site distribution, ca. 500-1100 A.D.

economy untenable, and brought a dramatic transformation in patterns of land use (fig. 3) (Irwin-Williams 1973; Reinhart 1967; Tainter and Gillio 1980: 45-48). Agriculture became the main basis of subsistence, possibly quite rapidly. By about 500 to 700 A.D. maize appears to have had a role in the economy as great as it had at European contact (Hegmon 1995). The use of pottery became widespread, as it was useful for reconstituting and cooking dried maize. The bow and arrow were adopted, suggesting a change in hunting strategies (Glassow 1972, 1980).

In the Arroyo Cuervo region the canyon heads, which had been occupied for perhaps 6,000 years, were abandoned some time after 600 A.D. in favor of the cultivable valley bottoms (fig. 4). The higher-elevation parts of the West Mesa were never again used as intensively. In the last few centuries A.D. there was a substantial occupation on the eastern rim of the West Mesa, along washes with gentle gradients suitable for floodplain agriculture (Frisbie 1967; Allan 1975; Tainter and Gillio 1980: 47). The labor requirements for cultivating, tending, and harvesting agricultural fields, and the difficulty in transporting large harvests, meant that hereafter populations had to be largely sedentary (Wills and Huckell 1994: 50-51). As mobility was reduced, land use became increasingly intensive in the vicinity of sedentary communities.

The period from about 1000 to 1400 A.D. witnessed even more dramatic transformations. The Rio Puerco Valley supported a dense agricultural population (fig. 5) (Fritz 1973; Washburn 1972, 1974; Burns 1978; Pippin 1987), which farmed the floodplain and its side drainages. In some years they had temporary fields in the Arroyo Cuervo but this area was, for the most part, abandoned. Populations that clustered around a site called Guadalupe Ruin were part of a regional political and economic system centered in Chaco Canyon to the west (Pippin 1987; Tainter 1984, 1988: 178-187, 1994; Tainter and Plog 1994). By 1350 A.D. the upper Rio Puerco Valley was abandoned by farming populations. The reasons for this are still

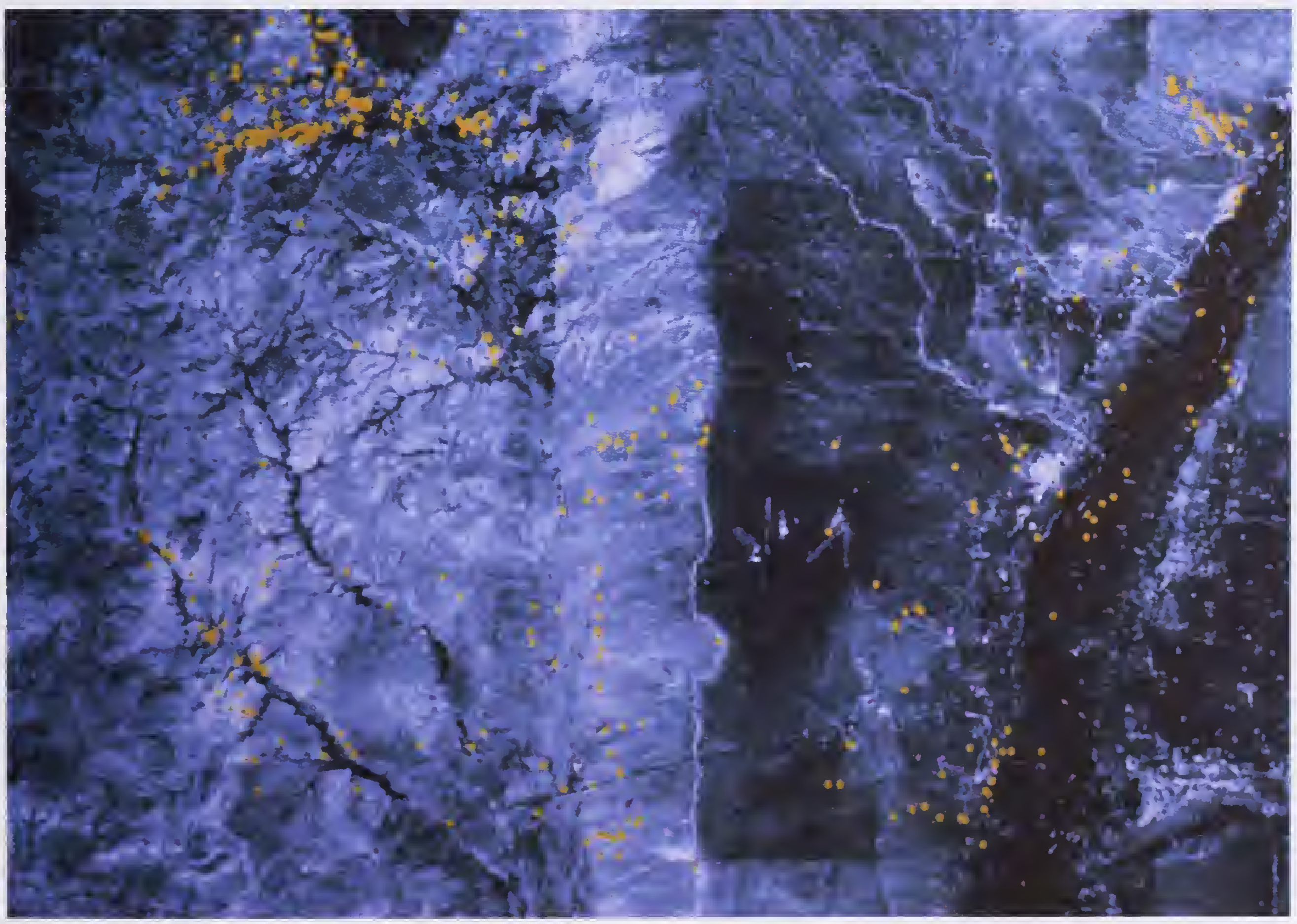


Figure 5. Pueblo III site distribution, ca. 1100-1300 A.D.

unclear, but then as now the area is highly susceptible to erosion (Burns 1978).

The abandonment of the upper Rio Puerco was part of a broader process. During the course of the 14th century A.D. much of the upland areas of what are now western New Mexico, and eastern and northern Arizona, were abruptly abandoned. The populations that survived this crisis (Cordell 1995) concentrated thereafter in a few areas, including the Rio Grande Valley (fig. 6) (Wendorf 1954; Wendorf and Reed 1955; Collins 1975; Dickson 1979; Tainter n.d.). This area came to be used intensively for the first time, and large communities were established on a scale never seen before. The entire region experienced a profound discontinuity in its pattern of cultural evolution. Settlement patterns changed from dispersed to aggregated. Social complexity increased in response to the problems posed by large aggregations of people. Ritual systems of social integration, such as the Katchina Cult, were adopted (Schaafsma and Schaafsma 1974). Parts of the valley bottom were farmed at a level of intensity not seen again until the 19th century. In 12,000 years of native occupation, it was the most significant and far-reaching transformation in land and resource use.

PREHISTORIC SETTLEMENT AND DISTURBANCE PROCESSES

Although we need a much deeper understanding of these changes in land use, our present knowledge has implications for understanding ecosystem disturbance processes in prehistory. While there are various definitions in ecology of what constitutes a "disturbance" (e.g., the definitions cited in Lundquist, Geils, and Negron [1995: 78]; and Wright, Chapman, and Jimerson [1995: 259]), for this study a definition given to me recently by Russell Graham seems most useful: a disturbance is anything that alters a trajectory or a trend (personal communication, 1995). The mas-

Figure 6. Pueblo IV site distribution, ca. 1300-1600 A.D.

sive convergence of human populations on the northern and middle Rio Grande Valley in the 14th century A.D. would certainly appear to qualify. Within a few generations this area went from supporting a small, dispersed agricultural population, to supporting much of the remaining population from large parts of the Southwest. Communities of up to 2,000 to 3,000 rooms were built. Lands were cleared for agriculture, and every piece of wood useful for construction, cooking, or heating would quickly have been consumed within easy walking distance. The distribution and abundance of native plant and animal species would have been altered in a short time, as would nutrient cycling and the composition of soils. It is important to ask how Rio Grande Basin ecosystems would have evolved subsequently, and up to today, if this massive disturbance had not occurred.

This pattern of disturbance was continued and intensified with the Hispanic and Anglo-American intrusions in the 16th through 19th centuries. The Hispanic *entrada* in the 17th century would, at least initially, have amounted to little more than the replacement of the portion of the American Indian population that in the previous century had been lost to European diseases (cf. Ramenofsky 1987). Yet the Hispanic introduction of cattle and sheep had far-reaching environmental consequences, which became particularly acute with the incorporation of New Mexico into the North American and international economies in the 19th century (Scurlock 1995; Wozniak 1995). The Puebloan intrusion in the 14th century and the Euro-American settlement were the most severe disturbances to Rio Grande Basin ecosystems since the end of the Pleistocene.

The earlier role of hunter-gatherer populations in ecosystem processes of the Arroyo Cuervo and West Mesa presents a subtler problem. We know that in other parts of North America, hunting and gathering populations actively manipulated vegetation to increase the production of useable resources (e.g., Lewis 1973). Whether this was done prehistorically in the Arroyo Cuervo/West Mesa region is not yet known, but research elsewhere in the Southwest is showing how to investigate this possibility (Sullivan 1995). Certainly as population in the area grew, there would have been increasing pressures to manipulate vegetation. Even without such manipulation, the fact that there were 6,000 years of intense human use of this area suggests that the forager population was a major ecosystem component. Certainly the hunter-gatherers would have had a controlling influence on such factors as the distribution and abundance of seed-bearing plants, ungulates that they hunted, rodents that were attracted to their food stores, carnivore populations, tree growth in the pinyon-juniper zone, accessibility of water for wildlife, nutrient cycling, soil formation, and erosion. Over 6,000 years, humans were as integral to these ecosystems as nearly any other component. If disturbance is considered to be the disruption of a trend, then the human occupation of the Arroyo Cuervo and West Mesa suggests what some may consider a counterintuitive notion: the greatest disturbance to these ecosystems may have been the *withdrawal* of the human population in the 7th to 8th centuries A.D. Certainly a great variety of ecosystem structures and processes, which had been regulated for 6,000 years by gradually intensifying human use, would suddenly have had to establish new ranges of tolerance and adjust to new conditions.

CONCLUDING REMARKS

Ecosystem management is a developing field that has yet to delineate the full range of pertinent structures and processes. The human populations of North America have been an essential part of these structures and processes, even a controlling part in some cases. They can no more be left out of ecosystem analyses than can, for example, paleoclimate. In the Arroyo Cuervo and West Mesa areas, the processes of ecosystem adjustment after the human withdrawal should be understood before we can be confident that we know these systems well enough to manage them. Ecosystem research and management of the future has to combine the findings not only of contemporary environmental and social sciences, but of the historical sciences as well. It is from that combination, and only from that combination, that the delineation of historical reference conditions, ranges of variation, and disturbance processes will emerge.

ACKNOWLEDGMENTS

We are pleased to acknowledge the assistance of several people in the preparation of this paper.

Timothy Seaman of the Archeological Records Management System, New Mexico Historic Preservation Division, kindly prepared the data sets used in the analysis. Shirley Baros showed us the capabilities of the University of New Mexico Earth Data Analysis Center (EDAC), where the site distributions were plotted on a September 1992 Landsat image. Sarah Fruit prepared the data sets and Thomas Budge plotted and photographed the images. Finally we are grateful to Douglas Shaw and Deborah Finch for the invitation to prepare this paper. Their recognition of the need to integrate social, historical, and biophysical research in land management points to the direction in which all environmental research needs to proceed.

REFERENCES

Allan, William C. 1975. An archeological survey of a floodwater retarding structure in the Corrales watershed. In: Broilo, F. J.; Stuart, D. E., eds., Archeological reports, cultural resource management projects. Albuquerque, NM: University of New Mexico, Office of Contract Archeology, Working Draft Series 1: 144-158.

Bandelier, Adolph F. 1892. Final report of investigations among the Indians of the Southwestern United States, carried on mainly in the years from 1880-1885, part II. Boston, MA: The Archaeological Institute of America. Papers of the Archaeological Institute of America, American Series 4.

Burns, B. 1978. Tentative ceramic chronology for the middle Puerco Valley and chronometric analysis. In: Irwin-Williams, Cynthia, comp. Archaeological investigations in the area of the middle Puerco River Valley, New Mexico, May 1-December 1, 1978. Portales, NM: Eastern New Mexico University.

Campbell, John M.; Ellis, Florence Hawley. 1952. The Atrisco sites: Cochise manifestations in the middle Rio Grande Valley. American Antiquity. 17: 211-221.

Cartledge, Thomas R.; Propper, Judith G. 1993. Piñon-juniper ecosystems through time: information and insights from the past. In: Aldon, Earl F.; Shaw, Douglas W., tech. coords. Managing piñon-juniper ecosystems for sustainability and social needs. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report RM-236: 63-71.

Collins, Susan M. 1975. Prehistoric Rio Grande settlement patterns and the inference of demographic change. Boulder, CO: University of Colorado. Ph.D. dissertation. Ann Arbor, MI: University Microfilms.

Cordell, Linda A. 1995. Models and frameworks for archaeological analysis of resource stress in the American Southwest. In: Tainter, Joseph A.; Tainter, Bonnie Bagley, eds. Evolving complexity and environmental risk in the prehistoric Southwest. Santa Fe, NM: Santa Fe Institute. Studies in the Sciences of Complexity, Proceedings Volume XXIV. Reading, MA: Addison-Wesley: 251-265.

Cronon, William. 1983. Changes in the land: Indians, colonists, and the ecology of New England. New York: Hill and Wang.

Culbert, T. Patrick. 1988. The collapse of Classic Maya Civilization. In: Yoffee, Norman; Cowgill, George L., eds. The collapse of ancient states and civilizations. Tucson: University of Arizona Press: 69-101.

Dickson, D. Bruce Jr. 1979. Prehistoric pueblo settlement patterns: the Arroyo Hondo, New Mexico, site survey. Santa Fe, NM: School of American Research Press.

Frisbie, Theodore R. 1967. The excavation and interpretation of the Artificial Leg Basketmaker III-Pueblo I sites near Corrales, New Mexico. Albuquerque, NM: University of New Mexico. M.A. thesis.

Fritz, V. D. 1973. Settlement patterns in the Salado Canyon, New Mexico, Pueblo I-III (850- 1350 A.D.). Portales, NM: Eastern New Mexico University. M.A. thesis.

Glassow, Michael A. 1972. Changes in the adaptations of southwestern Basketmakers: a systems perspective. In: Leone, Mark, ed. Contemporary archaeology. Carbondale, IL: Southern Illinois University Press: 289-301.

Glassow, Michael A. 1980. Prehistoric agricultural development in the northern Southwest: a study in changing patterns of land use. Ramona, CA: Ballena Press. Anthropological Papers 16.

Gunn, Joel D. 1994. Global climate and regional biocultural diversity. In: Crumley, Carole E., ed. Historical ecology: cultural knowledge and

changing landscapes. Santa Fe: School of American Research Press: 67-97.

Hegmon, Michelle. 1995. Variability in food production, strategies of storage and exchange, and the pithouse-to-pueblo transition in the northern Southwest. In: Tainter, Joseph A.; Tainter, Bonnie Bagley, eds. Evolving complexity and environmental risk in the prehistoric Southwest. Santa Fe, NM: Santa Fe Institute. Studies in the Sciences of Complexity, Proceedings Volume XXIV. Reading, MA: Addison-Wesley: 223-250.

Irwin-Williams, Cynthia. 1973. The Oshara Tradition: origins of Anasazi Culture. Portales, NM: Eastern New Mexico University. Contributions in Anthropology 5(1).

Judge, W. James. 1973. PaleoIndian occupation in the central Rio Grande Valley in New Mexico. Albuquerque, NM: University of New Mexico Press.

Kay, E. Charles. 1995. Aboriginal overkill and native burning: implications for modern ecosystem management. Portland, OR: The 8th George Wright Society Conference on Research and Resource Management on Public Lands, 1995 April 17-21.

Lewis, Henry T. 1973. Patterns of Indian burning in California: ecology and ethnohistory. Ramona, CA: Ballena Press. Anthropological Papers 1.

Lightfoot, Kent G. 1979. Food redistribution among prehistoric Pueblo groups. The Kiva. 44: 319-339.

Lundquist, J. E.; Geils, B. W.; Negron, J. F. 1995. Integrating applications for understanding the effects of small-scale disturbances in forest ecosystems. In: Thompson, Joyce Elma, comp. Analysis in support of ecosystem management. Washington, DC: USDA Forest Service, Ecosystem Management Analysis Center: 77-86.

Pippin, Lonnie C. 1987. Prehistory and paleoecology of Guadalupe Ruin, New Mexico. Salt Lake City, UT: University of Utah. Anthropological Papers 107.

Ramenofsky, Ann F. 1987. Vectors of death: the archaeology of European contact. Albuquerque, NM: University of New Mexico Press.

Reinhart, Theodore R. 1967. Late Archaic cultures in the middle Rio Grande Valley: a study of the process of culture change. Albuquerque, NM: University of New Mexico. Ph.D. dissertation. Ann Arbor, MI: University Microfilms.

Schaafsma, Polly; Schaafsma, Curtis F. 1974. Evidence for the origins of the Pueblo Katchina Cult as suggested by Southwestern rock art. American Antiquity. 39: 535-545.

Scurlock, Dan. 1995. Environmental History. In: Finch, Deborah M.; Tainter, Joseph A., eds. Ecology, diversity, and sustainability of the middle Rio Grande basin. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report RM-268: 12-28.

Sullivan, Alan P. III. 1995. Risk, anthropogenic environments, and western Anasazi subsistence. In: Tainter, Joseph A.; Tainter, Bonnie Bagley, eds. Evolving complexity and environmental risk in the prehistoric Southwest. Santa Fe, NM: Santa Fe Institute. Studies in the Sciences of Complexity, Proceedings Volume XXIV. Reading, MA: Addison-Wesley: 145-167.

Tainter, Joseph A. 1984. Perspectives on the northern Mogollon boundary phenomenon. In: Upham, Steadman; Plog, Fred; Batcho, David G.; Kauffman, Barbara E., eds. Recent research in Mogollon prehistory. Las Cruces, NM: New Mexico State University Museum. Occasional Paper 10: 45-58.

Tainter, Joseph A. 1988. The collapse of complex societies. Cambridge: Cambridge University Press.

Tainter, Joseph A. 1994. Southwestern contributions to the understanding of core-periphery relations. In: Gumerman, George J.; Gell-Mann, Murray, eds. Understanding complexity in the prehistoric Southwest. Santa Fe, NM: Santa Fe Institute. Studies in the Sciences of Complexity, Proceedings Volume XVI. Reading, MA: Addison-Wesley: 25-36.

Tainter, Joseph A. 1995. Sustainability of complex societies. Futures. 27: 397-408.

Tainter, Joseph A. n.d. Synthesis of the prehistoric occupation and evaluation of the research design. In: Tainter, Joseph A., ed. [In press.] Final report of investigations: the Albuquerque sector of the Elena Gallegos Project. Albuquerque, NM: USDA Forest Service, Southwestern Region.

Tainter, Joseph A.; Gillio, David A. 1980. Cultural resources overview, Mt. Taylor area, New Mexico. Albuquerque and Santa Fe, NM: USDA Forest Service, Southwestern Region and USDI Bureau of Land Management, New Mexico State Office.

Tainter, Joseph A.; Plog, Fred. 1994. Strong and weak patterning in Southwestern prehistory: the formation of Puebloan archaeology. In: Gumerman, George J., ed. Themes in Southwest prehistory. Santa Fe, NM: School of American Research Press: 165- 181.

Washburn, Dorothy K. 1972. An analysis of the spatial aspects of the site locations of Pueblo I-III sites along the middle Rio Puerco, New Mexico. New York, NY: Columbia University. Ph.D. dissertation. Ann Arbor, MI: University Microfilms.

Washburn, Dorothy K. 1974. Nearest neighbor analysis of Pueblo I-III settlement patterns along the Rio Puerco of the east, New Mexico. American Antiquity. 39: 315-335.

Wendorf, Fred. 1954. A reconstruction of northern Rio Grande prehistory. American Anthropologist. 56: 200-227.

Wendorf, Fred; Reed, Erik. 1955. An alternative reconstruction of northern Rio Grande prehistory. El Palacio. 62: 131-173.

Wills, W. H.; Huckell, Bruce. 1994. Economic implications of changing land-use patterns in the Archaic. In: Gumerman, George J., ed. Themes in Southwest prehistory. Santa Fe, NM: School of American Research Press: 33-52.

Wozniak, Frank E. 1995. Human ecology and ethnology. In: Finch, Deborah M.; Tainter, Joseph A., eds. Ecology, diversity, and sustainability of the middle Rio Grande basin. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report RM-268: 29-51.

Wright, Kenneth E.; Chapman, Laura M.; Jimerson, Thomas M. 1995. Using historic range of vegetation variability to develop desired conditions and model forest plan alternatives. In: Thompson, Joyce Elma, comp. Analysis in support of ecosystem management. Washington, DC: USDA Forest Service, Ecosystem Management Analysis Center: 258- 266.

Human impacts on riparian ecosystems of the Middle Rio Grande Valley during historic times

Frank E. Wozniak[1]

Abstract.—The development of irrigation agriculture in historic times has profoundly impacted riparian ecosystems in the Middle Rio Grande Valley of New Mexico. A vital relationship has existed between water resources and settlement in the semi-arid Southwest since prehistoric times. Levels of technology have influenced human generated changes in the riparian ecosystems of the Middle Rio Grande Valley.

The relationship of humans with the riparian ecosystems of the Middle Rio Grande Valley has been and is complex. The foundations for an understanding of historic human land uses are to be found in environmental, cultural, political and socio-economic factors and processes. The relationship of humans with the land is based on and regulated by resource availability, environmental conditions, levels of technological knowledge, political and socio-economic structures and cultural values regarding land and water and their uses.

During historic times, the riparian resources of the Middle Rio Grande Valley have been utilized by three groups: American Indian, Hispanic and Anglo-American. While some studies of cultural values regarding land and water do exist, these studies have tended to be simplistic. Studies of cultural values that do not romanticize certain groups and demonize others are a fundamental foundation of any understanding of the relationship between humans and riparian ecosystems.

The levels of technological knowledge available and utilized within the Middle Rio Grande Valley have profoundly influenced human impacts on riparian ecosystems. The outlines of these varying levels of technology have been broadly defined but specifics have yet to be developed by researchers. These elements should include the introduction of intensive irrigation agriculture by the Spanish in the 17th century and building of railroads by the Anglo-Americans in the 19th century as well as the impacts of the introductions of plants and animals by the Euro-Americans throughout the last 450 years.

In this paper, we will look at the development of irrigation agriculture and its impacts on riparian ecosystems in the Middle Rio Grande Valley of New Mexico during historic times (e.g. after A.D. 1540). A vital relationship has existed between water resources and settlement in the semi-arid Southwest since prehistoric times (Wozniak 1987). Levels of technology have profoundly influenced human impacts on and human generated changes in riparian ecosystems of the Middle Rio Grande Valley. At the most simple level, the differences between stone tool and metal tool based subsistence systems are quite significant. This does not mean that stone tool technologies would not and did not enable humans to alter ecosystems. The stone tool technologies of prehistoric Indian populations in the Middle Rio Grande Valley did have significant impacts on ecosystems throughout New Mexico. Major transformations in Indian impacts did develop as a result of the introduction of metal tools by Euro-Americans in the late 16th

[1] *Historian and consultant to the Forest Service, Southwestern Regional Office, Albuquerque, NM.*

century. With metal tool based technologies, Indian impacts on riparian ecosystems of the Middle Rio Grande Valley were intensified. The overall human impacts on these riparian ecosystems were expanded by direct Euro-American utilizations of the Middle Rio Grande Valley in the 17th and 18th centuries.

With the Spanish colonization of New Mexico in 1598 came the introduction of intensive irrigation agriculture into New Mexico. What is surprising about irrigation agriculture in the Rio Grande Valley is its relative rarity among the Pueblo Indians before Spanish settlement (Wozniak 1987). A common assumption exists about irrigation and the prehistoric Pueblo Indians in New Mexico which is found in virtually all popular discussions of and most scholarly studies on the Pueblo Indians, namely that all Pueblo groups in the Rio Grande Valley engaged in irrigation agriculture in prehistoric times and that the Coronado Expedition of 1540-1542 found the Pueblo Indians engaged in the extensive practice of irrigation agriculture. Neither of these assumptions is accurate and neither is founded on any scientific or documentary evidence. Recently, a few researchers (Cordell 1979; Earls 1985; Wozniak 1987) have expressed reservations with regard to the prevalent notion that the Pueblo Indians were ancient irrigators in the Rio Grande Valley.

The Anasazi, who were the prehistoric ancestors of the Pueblo Indians, invested considerable energy in soil and moisture conservation facilities such as check dams, terraces and grid gardens. In their subsistence strategies, the Anasazi engaged primarily in extensive agricultural systems based on ak-chin or floodwater farming. In looking at Anasazi agriculture, it is important to distinguish between water conservation systems and water diversion systems-only the latter are irrigation.

A review of the archeological record for the Rio Grande Valley of New Mexico shows considerable evidence of a variety of water and soil conservation features and of floodwater farming systems. However, there is no archeological evidence of any **prehistoric** irrigation features or irrigation systems in the Rio Grande Valley. As an aside, it should be noted that the Hohokam in central and southern Arizona did engage in substantial amounts of irrigation agriculture which is documented in the archeological record.

In the Middle Rio Grande Valley, the Anasazi developed a successful and diversified subsistence strategy that combined floodwater farming with hunting and gathering. As a result, they avoided the problems inherent in farming on the Rio Grande floodplain - floods, salinization, dense vegetation, disease and insects. Anasazi stone tool technology was adopted to sandy soils for floodwater farming not to irrigation agriculture in heavy bottomland soils.

In late 1540, the Coronado Expedition reached the Tiquex province that covered most of the present Middle Rio Grande Valley. The contemporary accounts of the Coronado Expedition (Hammond and Rey 1940) do not report any irrigation agriculture being practiced by any Pueblo Indians. The expedition narratives did report irrigation systems among the Indians of Sonora but none in New Mexico (Riley 1987). Records from late 16th century Spanish expeditions into New Mexico reported that irrigation agriculture was practiced by some Pueblo Indian communities in some parts of New Mexico (Hammond and Rey 1966). The Rodriquez - Chamuscado expedition of 1581 reported a Pueblo Indian irrigation system in the lower portion of Las Huertas Creek near its confluence with the Rio Grande; Las Huertas Creek was a perennial stream until developments in the early 20th century. The accounts of the Espejo expedition of 1582-1583 reported irrigation in the Piro provenience (near Soccorro) on the sandy bottomlands with water being taken from side channels of the Rio Grande (Earls 1985). The Espejo expedition narratives also reported irrigation along the Rio San Jose near Acoma Pueblo and along Nutrias Creek at Zuni Pueblo. In the late 16th century, some Pueblos engaged in some irrigation agriculture but floodwater and other forms of dryland farming were the exclusive form of agriculture among most Puebloan groups and a major component among those few Pueblos who used some form of irrigation (Wozniak 1987). The agricultural commitment of the Pueblo Indians in the 16th century was to extensive floodwater farming systems and other strategies of water and soil conservation. The onset of Spanish settlement changed this. One of the first recorded activities of Spanish settlers in 1598 was the construction with Indian labor of an acequia (irrigation ditch) near San Juan Pueblo to provide

water for irrigation agriculture (Hammond and Rey 1953).

When the Spanish settled in New Mexico at the end of the 16th century, they brought with them new technologies and a variety of new domesticated plants and animals. These introduced species along with the new political, socio-economic and ideological structures which were imposed by the Spanish significantly altered Puebloan diets, economic structures and land use patterns.

Given the vital relationship between water and settlement in all semi-arid environments of the North American West, including New Mexico, it is not surprising that the Spanish of the 17th, 18th, and 19th centuries gravitated to the Rio Grande Valley and its tributaries. Spanish settlement depended upon irrigation agriculture for its economic base and, therefore, for its survival. Spanish missionaries and Spanish government officials imposed an irreversible reliance on irrigation agriculture upon the Pueblo Indians during the 17th century (Wozniak 1987). This combined socio-economic and technological change irretrievably undermined and altered traditional Puebloan subsistence systems, land use patterns and lifeways. In addition to a plethora of domestic livestock (sheep, goats, cattle, horses, mules, hogs, chickens, etc.) and new cultigens (wheat, barley, oats, onions, lettuce, watermelon, fruit trees, etc.) the Spanish also introduced native Mexican Indian crops such as tomatoes, chiles, cultivated tobacco and new varieties of corn and beans. These introduced species along with the introduction of metal tools such as axes, and metal tipped plows had a significant and sometimes adverse impact on native flora, fauna and soils. The role of metal tools and their impact on ecosystems before the 19th century should not be exaggerated since metal tools were generally in short, even critically short, supply throughout the 17th and 18th centuries in New Mexico.

With the colonization of New Mexico by the Spaniards, irrigation and irrigation development entered into a new era in the Rio Grande Valley (Wozniak 1987). The introduction of new crops, such as wheat, that required irrigation in order to produce harvests in semiarid New Mexico encouraged the development and/or expansion of Pueblo Indian irrigation. The Spaniards insisted that the Indians grow these crops, particularly wheat, so that the Spaniards could obtain their customary foodstuffs even in New Mexico. At least part of the tribute that the Spanish regime required from the Puebloans was exacted in the form of wheat, so the Indians had to irrigate in order to meet these demands. Other tribute demands for foodstuffs would also push the Puebloans toward intensive (i.e., irrigation) agriculture during the seventeenth century, with considerable disruptive consequences for Puebloan society in New Mexico. Irrigation agriculture produced ever expanding impacts on riparian ecosystems as the bosques were cut down to expand the field systems.

During the seventeenth century, the Spanish settlers in New Mexico survived on tribute in food and labor collected from the Puebloans under the *encomienda* and *repartimiento* systems (Scholes 1937, 1940). The Spanish missions or *reducciones* concentrated Puebloan populations into a much smaller number of pueblos than had been occupied before the arrival of the Spaniards. The reducciones were established for religious, political, economic, and military reasons and served to enhance Spanish control and supervision over the native Indian populations (John 1975; Scholes 1937, 1940). Concentration of the heretofore scattered Puebloan settlements also enabled both ecclesiastical and secular authorities to exploit the Indian labor force more effectively and to levy tribute. Tribute demands and the reducciones themselves often drove the Puebloans to escape Spanish control by withdrawing into the mountains or joining the nomadic Indian tribes (Hammond and Rey 1953).

Throughout the seventeenth century, the Spaniards steadily increased their demands for native labor and goods while the labor force was being progressively reduced by disease and warfare (Earls 1985). Missionization appears to have produced the first of the major population declines that then continued as a result of epidemics and drought (Earls 1985). Demands for native labor by both the encomenderos and the friars along with the increasing European population placed strong pressures on the Puebloans to improve their productivity in order to supply food for both groups. These pressures led to an increased and in some cases a virtually exclusive reliance on irrigation agriculture (Earls 1985). The Spaniards encouraged the development of Puebloan irrigation farming not only to ensure the increased produc-

tivity that would supply them with food and to obtain introduced European crops but also because irrigation agriculture made possible the concentration of Puebloan populations in the *reducciones*. The friars thus intended both to increase Puebloan productivity and to maintain a newly imposed sedentism among the New Mexico Pueblos. Dry farming was replaced by more intensive agricultural strategies involving fields irrigated by diversions of water through ditches. At the same time hunting virtually disappeared, to be replaced by livestock herding (Earls 1985). The gathering of wild plants and plant products declined as the Puebloans were tied to their irrigated field in their efforts to meet the demands of the colonists and missionaries (Earls 1985).

Agricultural intensification through irrigation was a demanding system with regard to labor, and the requirements of the system were difficult to meet owing to the decline in Indian populations. Such intensification was necessary, however, if the alimentary demands of the friars and encomenderos and the simultaneous demands for other goods and services were to be met (Earls 1985). Contrary to Ellis's (1970) contention that the Spaniards found irrigation widespread and flourishing in the Rio Grande Valley, it was the institution of the *reducciones* that produced a rapid change in the Puebloan subsistence system from expansive to intensive agriculture. This increased and heretofore unnecessary dependence on agriculture led to a decrease in hunting, gathering, and trade in subsistence goods with the nomadic tribes. Mineral deposits, although present in several areas of New Mexico, were insignificant and unexploited in the 17th century. Apart from an erratic pinyon crop, and the relatively unimportant collection of wild animal skins and cotton textiles, there were virtually no exploitable natural resources which were not already available in quantity in the mining districts of Chihuahua - New Mexico's only potential market.

Economic exploitation, religious persecution, and the failure of the Spaniards to protect the Puebloans from nomadic raiders culminated in the Pueblo Revolt of 1680 (Hackett 1942; John 1975). After decimating the Spanish settlements and driving the remaining settlers from the northern Rio Grande Valley, the Puebloans shed Spanish religion and culture but retained Spanish crops and technology, both civilian and military (Hackett 1942). The continuing legacy of Spanish colonization could be seen in the residual importance of irrigation agriculture. Despite the directions and wishes of the religious leaders of the Pueblo Revolt, the Pueblo Indians continued to utilize Spanish crops and technology.

Puebloan factionalism and calculated economic warfare ultimately enabled Diego de Vargas to reduce the Pueblos once again to Spanish rule between 1692 and 1694 (Espinosa 1942). Only Vargas himself was authorized to have an encomienda after the Reconquest; all other Spanish settlers were to support themselves by their own labors. Economic conditions, however, forced the newly returned Spaniards to rely upon a system of tribute in food and labor from the exhausted pueblos that, in its operations and efforts, resembled the discredited encomienda and repartimiento system. These exactions drove most of the Puebloans into a second revolt in 1696 (Espinosa 1942). The Spaniards crushed the new revolt with the assistance of those pueblos that did not join the rebellion (Espinosa 1942). After 1697, a new economic regime was established in New Mexico, one that centered on community land grants rather than encomiendas. Internecine warfare among the Puebloans during the Revolt and Reconquest led to the abandonment of many 17th century pueblos, particularly in the Middle Rio Grande Basin. These abandonments had a profound effect on 18th century resettlement and land use patterns (Wozniak 1987).

The century following the reconquest is crucial to an understanding of the cultural diversity of the Middle Rio Grande Basin. Throughout most of the 18th century, New Mexico was not an active participant in the developing colonial world system of which it was an almost forgotten part. More significant were raids by and warfare with New Mexico's nomadic neighbors: the Navajos, the Apaches, the Utes and the Comanches. The alternating periods of war and peace had a major impact on settlement patterns and resulted in periods of expansion followed by periods of settlement contractions and abandonments (Wozniak 1987). Warfare between the nomadic Indians, and the Spanish and the Puebloans affected land uses in the Middle Rio Grande Basin until after the American Civil War.

The 18th century also witnessed the gradual compartmentalization of Puebloan culture and society. On the one hand, Puebloan communities needed to co-exist with the dominant Hispanic culture; on the other hand, there was the equally obvious desire to maintain individual Puebloan traditions and identity. Out of the 18th century, there developed the Puebloan and Spanish Colonial cultural traditions which are still evident on the landscapes of the Middle Rio Grande Basin. Both traditions had to cooperate and interact in order to survive in the semi-arid environment of New Mexico and to defend themselves against attacks by the semi-nomadic Indian tribes that surrounded New Mexico.

With the reconquest of New Mexico in the mid 1690s, the Spaniards instituted a new settlement system that transformed the way they utilized the resources of New Mexico (Wozniak 1987). Before the Pueblo Revolt the Spaniards had occupied New Mexico with a small number of settlers who held large tracts of land. These seventeenth century settlers grazed livestock and depended upon the Puebloans to produce surpluses of food as well as products such as woven goods, salt, and piñon nuts. After the Reconquest, because a secure hold on New Mexico had a higher value than the extraction of economic wealth, the Spanish government made grants of land (*mercedes*) to ensure the effective occupation of New Mexico by means of self-sufficient farming and herding communities (Westphall 1983).

In place of a small number of exploitive encomiendas, which had proved to be a political, military, and economic disaster, the Spanish authorities established an ever-expanding number of land grants on which the Hispanic settlers supported themselves through agriculture and stock-raising (Carlson 1971). In the early days after the Spanish reconquered New Mexico, a number of individual land grants were given to people who had been prominent in the Reconquest. Though given to individuals, these were not encomiendas; the recipients were expected to support themselves by their own endeavors and those of their extended families and servants (Carlson 1975; Van Ness 1979). Indian labor was virtually unavailable owing to the catastrophic population decline of the late 17th century. This decline continued at a reduced level in the 18th century, while the non-Indian population steadily expanded. At the same time, the Spaniards were prohibited from exploiting what little Indian labor might have been available (Simmons 1969). The Indian pueblos settled into a system of local self-sufficiency under the religious, but not economic, supervision of the mission friars (Adams and Chavez 1956). Most land grants in the eighteenth century were given to groups rather than individuals, in an effort to settle as many people as possible on the land and in order to provide for defensible settlements (Simmons 1969; Westphall 1983). New Mexico became a region of small, self-sufficient Puebloan and Hispanic communities, held together by fear of nomadic raids and by the necessities of mutual defense.

In order for a settlement to succeed, irrigable land was necessary (Carlson 1971; Ressler 1968; Van Ness 1979). The accessibility of water to cultivate bottomlands was a primary consideration in the grants of land by the Spanish government. Subsistence agriculture employing irrigation farming and livestock herding was the economic basis for these settlements. Consequently land grants were made primarily along the Rio Grande and the Rio Chama and their perennial tributaries. The irrigable lands on each grant were divided among the settlers, while the rest of the land was held in common for pasture and woodland (Van Ness 1979; Westphall 1983). While Spanish colonial ordinances required, and the times in which the grants were made frequently dictated, that settlements be compactly organized for defense, most New Mexico land grant settlements were straggly communities of dispersed ranchos (Simmons 1969). Formal plazas were rare, despite the threat of Indian raids. Even the villas of Santa Fe, Santa Cruz, and Albuquerque were scattered over large areas in order for farmers to live near their irrigable fields (Simmons 1969). The expanding number of land grant settlements in the 18th and 19th century had far reaching impacts on riparian ecosystems throughout the Rio Grande Valley; these included alterations in stream flows and impacts on native vegetation, especially the bosques. The bosques suffered particularly significant reductions in the first half of the 19th century.

The long-lot system which prevailed on most land grants was developed to accommodate community land grants and as a response to local

conditions in the Rio Grande Valley of northern New Mexico. However, this system of property division did not resemble the Puebloan field systems of the 17th or 18th centuries. Long-lot farms developed as a means of growing introduced crops that required irrigation in a semiarid environment where both land and water resources were limited (Carlson 1975; Van Ness 1979). The system assured settlers maximum access to limited water resources and proved to be a practical and equitable method of partitioning irrigable lands among the large numbers of settlers required by military necessities. The resulting small subsistence farms never produced significant agricultural surpluses nor were they intended to do so (Carlson 1975). Colonial policy was not directed toward economic prosperity but toward the successful occupation of New Mexico, which the defense of New Spain was deemed to require (Carlson 1975; John 1975).

In the Rio Abajo, where Puebloan populations south of the confluence of the Rio Grande and Rio Jemez had virtually disappeared, arable land was more plentiful, particularly along the Rio Grande; extensive grazing lands were also available in the Middle Rio Grande Basin (Wozniak 1987). Water, also, was more securely available and more manageable for irrigation purposes in the Rio Abajo than in the Rio Arriba, especially south of San Felipe Pueblo. The continual threat and often devastating impact of raids by nomadic Indians limited expansion, however, except in the Bernalillo and Albuquerque areas.

Little changed in the formalities of obtaining land grants under the Mexican regime, and the vicissitudes of settlement remained much the same as well. The total area given in land grants between 1821 and 1846, however, probably exceeded that granted during the preceding 125 years (Westphall 1983). Most of these grants were outside the Rio Grande Valley and placed large areas of grazing land under the control of individuals in what can only be termed an orgy of deliberate fraud and rapacity by prominent New Mexicans, aided and abetted by Mexican government officials in New Mexico. This raid on the public domain had precedents in the grazing grants west of the Rio Puerco in the 1760s. The Mexican period grants set the patterns for land use that would prevail in the Middle Rio Grande Basin throughout the 19th and into the 20th century. Trade with the Anglo-Americans, the incipient development of a livestock industry and some mining began the gradual transformation of the economy and land use patterns of the Middle Rio Grande Basin. These changes included both more extensive and intensive utilization of resources outside of the main valley.

Throughout the eighteenth century and first half of the nineteenth century the Indian pueblos suffered from declining populations and had to compete with Hispanic settlers for arable land and to a lesser extent for water. Unfortunately information regarding Puebloan irrigation systems is scarce and spotty, but enough can be derived from ecclesiastical reports to provide an adequate picture of Puebloan irrigation during the Spanish and Mexican periods. The best and most extensive report on the Pueblo Indians was that of Fray Dominguez from the latter part of the eighteenth century, but other, less comprehensive reports also exist (Adams 1954; Adams and Chavez 1956; Morfi 1932).

When the Americans occupied New Mexico in 1846, they found a largely agrarian society that was concentrated in the Rio Grande Valley and depended for its survival upon irrigation agriculture and raising livestock. Both Hispanic and Puebloan communities controlled and managed the irrigation systems that covered most of the irrigable lands along the mainstream of the Rio Grande and its tributaries.

Just prior to the annexation of New Mexico by the United States, Josiah Gregg visited the territory on several occasions during the 1830s. Gregg (1954) noted the fertility of the bottomlands and the barrenness of the unirrigated uplands. New Mexican agriculture was primitive by American standards. The crude plows were used only on loose soils; most land was cultivated with the hoe alone (Gregg 1954). Nearly all of the farms and settlements in New Mexico were located in valleys with perennial streams. In some valleys, crops were regularly stunted by the seasonal depletion of stream flows. One acequia madre was generally sufficient to convey water for the irrigation of an entire valley or the fields of one town or settlement (Gregg 1954). Community ditches were most common; private ditches were relatively rare (Gregg 1954). New Mexicans in the late Mexican

period grew mostly corn and wheat under a system of subsistence agriculture (Gregg 1954). While the scope and extent of irrigation activities in the Rio Grande Valley had steadily expanded in the Spanish and Mexican periods, the nature of irrigation agriculture had remained very much the same. Expansion of irrigation systems in the Rio Grande Valley was strictly a response to population growth. The primary focus on subsistence agriculture and livestock herding persisted in the Rio Grande Valley for some time after the American annexation of New Mexico under the Treaty of Guadalupe Hidalgo.

After the arrival of the railroads in the late 1870s and early 1880s, irrigated acreage in the Middle Rio Grande Basin expanded substantially until the 1890s when drought, upstream development, salinization, and defective drainage brought expansion virtually to a halt (Wozniak 1987). Although irrigated acreage had expanded, the actual irrigation systems and their organizations had changed very little between 1846 and 1910. In the Middle Rio Grande Valley, most expansion after 1846 took place in areas where raids by nomadic Indians had caused earlier attempts at settlement to fail.

The vast majority of farmers in 1910 were still Puebloan or Hispanic New Mexicans. Increasing numbers of Anglo-Americans had begun to engage in irrigation agriculture, but most were too poor to introduce modern irrigation technology (Wozniak 1987). The real impact of Anglo-Americans on the New Mexican economy during the Territorial period (1846-1912) was in the development of a livestock industry with its accompanying infrastructure of railroads and market towns. Most of the essential developments in the livestock industry in the Territorial Period took place away from the Rio Grande on the uplands and plains that surrounded the valley. The emergence of large scale sheep and cattle herding had significant impacts on ecosystems of the Middle Rio Grande Basin, particularly on soils, native vegetation and water resources.

With the American acquisition of New Mexico came the beginning of the end of the economic stability that New Mexican subsistence farmers had experienced for over a century (Wozniak 1987). While the stability of this adaptation gradually disappeared, the technology of irrigation and the methods of irrigation agriculture that were used changed very little for most farmers in the Rio Grande Valley until after the 1920s. The Anglo-Americans introduced changes in the New Mexican economy that altered settlement systems, land use patterns and the utilization of natural resources not only along the mainstream of the Rio Grande but also in the more marginal areas of the Middle Rio Grande Basin. Exploitation of minerals, grasslands, and forests as a part of the new, commercial economy of New Mexico opened portions of the ecosystems of the Middle Rio Grande Basin to more intensive use than the preceding subsistence economy had found possible or necessary.

However, the most immediate and profound impacts of the new economics of the Anglo-Americans came along the mainstream of the Rio Grande itself. By the early 1890s, serious problems had emerged in the irrigation agriculture of the Rio Grande Valley. Drought, which had struck sporadically in the 1880s, became acute in the early 1890s (Wortman 1971); by 1889 the Rio Grande below Albuquerque literally dried up for four months of the year. Stream flow had been seriously depleted by rapid development of irrigation agriculture in the San Luis Valley of Colorado; the effects on downstream users were dramatic and ultimately led to federal intervention (Follett 1896; Harper et al. 1943; Harroun 1898; Yeo 1910, 1928).

Ironically, at the same time that the Rio Grande was being seasonally depleted, lands in the middle Rio Grande Valley from Cochiti to San Marcial, especially between Bernalillo and La Joya, were becoming waterlogged and thus not amenable to cultivation (Clark 1987; Harper et al. 1943; Harroun 1898). Sedimentation in the Rio Grande resulting from decreased flows had caused the bed of the main channel to aggrade; as a result, the water table in many parts of the valley had begun to rise. Waterlogged lands had always been a problem near the Rio Grande itself owing to poor drainage and wasteful irrigation practices; under traditional agricultural methods, excess water in the acequias was simply dumped onto low-lying lands at the end of the acequia. Only a small percentage of ditches had facilities for returning the excess flow to the Rio Grande or delivering the water to downstream ditches. Each ditch system, of which there were dozens, was independent; no plan or organization to integrate the multitude of irrigation

systems in the middle Rio Grande Valley existed or was deemed necessary.

Though more urbanized and subject to outside influences than their neighbors to the north, residents of the middle Rio Grande Valley maintained patterns of agriculture that were remarkably traditional in the period before the 1920s (Harper et al. 1943). After the early 1880s and the arrival of the railroad, some commercial agriculture was introduced into the area around Albuquerque, Belen, and Socorro, but for the most part irrigation agriculture preserved its traditional orientation toward subsistence farming. At least 90 percent of the farmers were Hispanic or Puebloan, and approximately 90 percent of the irrigated acreage was farmed by them (Natural Resources Committee 1938). Nonetheless, irrigated acreage did expand in the middle Rio Grande Valley in the 1860s to early 1890s.

Beginning in the mid 1890s, droughts, sedimentation, aggradation of the main channel, salinization, seepage, and waterlogging caused an overall decline in irrigable acreage available in the middle Rio Grande region. The total amount of actual irrigated acreage remained relatively stable as previously uncultivated lands were brought into production to replace adversely affected acreage.

Much of the potentially irrigable acreage in the Middle Rio Grande Valley had been damaged by poor drainage and the rising water table and had been retired from production by the early twentieth century (Clark 1987; Dortignac 1956; Wortman 1971); this also resulted in the reemergence of the bosques in the Middle Rio Grande Valley. Thousands of acres were rendered unusable by the related problems of waterlogging and alkalinization; at the same time floods were frequent and often devastating. The flood of 1874 destroyed almost every building between Alameda and Barelas (Carter 1953). In 1884, Tome, Valencia, and Belen were under water during the spring floods. The flood of 1886 wiped out part of the pueblo of Santo Domingo, and a new church had to be built. In 1904 most of the bridges on the Rio Grande were destroyed by a late summer flood. The spring flood of 1905 washed away the community of Tome.

As early as the 1890s, the desirability of reorganizing the middle Rio Grande Valley irrigation systems was recognized by a few individuals. The need for a unified and rationalized system of irrigation and drainage was great, but such a development was hampered by misunderstanding and mistrust (Linford 1956). Local residents who were mostly Hispanic or Puebloan were naturally reluctant to surrender or assign water rights to private irrigation companies which were mainly Anglo-American enterprises in return for the promise of a more secure water supply in the future. Such a hesitancy was well founded; 90 percent of the private irrigation companies in the western United States went bankrupt—hardly a record to engender confidence in a privately sponsored reorganization of the middle Rio Grande Valley's irrigation systems (Wozniak 1987).

The late 19th and early 20 century also witnessed the breakup of community land grants and the common lands (ejido) as an indirect consequence of land grant adjudications by the U.S. Surveyor General and the Court of Private Land Claims. Except for the construction of larger flour mills and the centralization of distribution networks as a result of railroad constructions, agriculture in the Middle Rio Grande Basin changed very little before the 1920s from its centuries old system of irrigation farming. Frustrated in that area by antiquated farming methods, Anglos were constantly advocating "modern" approaches to and techniques of farming.

In 1879, the long awaited railroad arrived in New Mexico. The railroads immediately superseded the limited trade on the Sante Fe Trail and were able to transport larger masses of goods more quickly then the old system of wagon transportation. Connections with the eastern United States spurred the growth of new industries in New Mexico, including the Middle Rio Grande Basin. These included the livestock industry in sheep and cattle, and natural resource extraction in minerals and lumber. The railroads also directly spurred population growth though employment in construction and operations; by 1920 over half of Albuquerque's male heads-of-households worked for the Santa Fe Railroad.

Physical resources deteriorated in the middle Rio Grande Valley from the 1890s to the mid 1920s (Harper et al. 1943). Water shortages resulting from drought and especially from over-exploitation of surface water for irrigation in the San Luis Valley were frequent throughout the period after the early 1880s (Conkling and Debler 1919; Follett

1896; Gault 1923; Hodges 1938; Yeo 1910). These shortages were often tragically combined with devastating floods (Carter 1953; Yeo 1943). Water shortages particularly affected the annual flows on the middle and lower Rio Grande, producing increased sedimentation and dramatic channel aggradation in the early twentieth century that choked the ditches (Clark 1987; Harper et al. 1943). The aggradation of the main stream channel increased the frequency and destructiveness of floods and also contributed to the waterlogging of arable lands in the middle and lower valley through lateral seepage and raised water tables (Burkholder 1928; National Resources Committee 1938). Waterlogging was frequently accompanied by salinization and alkali poisoning of soils (Conkling and Debler 1919; Harper et al. 1943). The changes in the hydrology of the valley were not the only causes of waterlogging and its accompanying effects on arable lands. Traditional irrigation practices in the middle valley encouraged and frequently were a primary immediate cause of arable acreage going out of production (Stewart 1936). The combined effect of all of these factors was a decline in irrigation agriculture in the middle Rio Grande Valley (Harper et al. 1943). Drought in the 1920s and 1930s had similar effects on the grasslands of the Middle Rio Grande Basin. Overgrazing reduced the cover grasses and contributed to serious soil erosion.

Concern over the deterioration of conditions in the middle Rio Grande Valley gradually grew in the 1920s (Burkholder 1928; Linford 1956). In 1921, the State Legislature created the Rio Grande Survey Commission, which was to study conditions in the middle valley in cooperation with the U.S. Reclamation Service (Hedke 1925). Finally in August, 1925, the Middle Rio Grande Conservancy District (MRGCD) was organized. By this time, two-thirds of the arable bottomlands within its boundaries were subject to seepage or were waterlooged (Burkholder 1928; Conkling and Debler 1919).

Over the next three years an official plan for reclamation, flood control, and irrigation was developed; the plan was presented in its final form by the chief engineer of the district, Joseph L. Burkholder, in 1928. The plan covered flood and river control, irrigation (especially diversion dams and main canals), drainage, water supply (a reservoir at El Vado), management of Indian lands belonging to five pueblos (Congressional legislation was needed in order to include Pueblo lands within the Middle Rio Grande Conservancy District), and sedimentation control (dealing with aggradation of the Rio Grande, channel shifts, lateral seepage, and waterlogged lands). In March, 1928, Congress authorized the Secretary of the Interior to enter into an agreement with the Middle Rio Grande Conservancy District for irrigation, drainage, and flood control on the lands of the pueblos of Cochiti, Santo Domingo, San Felipe, Santa Ana, Sandia and Isleta (Clark 1987). The MRGCD and its projects would transform Middle Rio Grande Basin agriculture in the 1920s, 1930s, 1940s and 1950s.

The arrival of modern irrigation technology not only meant a reorganization of the irrigation systems, a renovation of the facilities, and a rationalization of the structure of irrigation but also the infusion of outside influences and a tremendous escalation in the costs of irrigation (Wozniak 1987). Much of the latter impact was absorbed by the largesse of the federal government, which wrote off or massively subsidized the costs of irrigation agriculture in the Rio Grande Valley as it did in the rest of the arid American West. The changes in the character of irrigation agriculture in the middle Rio Grande Valley of New Mexico included:

- The appearance of modern surveyed ditch alignments to replace the old meandering systems;
- The construction of a small number of concrete diversion structures to replace the multitudes of primitive head works;
- Construction of large water storage structures to provide a virtually guaranteed source of water during the irrigation season; and
- The institution of operation and maintenance methods using heavy machinery to replace human beings with shovels.

Many of the old problems of flooding, sedimentation, waterlogging, alkali poisoning, and unreliable water supply were resolved or at least held in check, but they were replaced by new problems related particularly to finances, especially maintenance costs and reimbursement of construction costs. The new problems have proved to be much more intractable than the old ones (Wozniak 1987).

LITERATURE CITED

Adams, Eleanor B. 1954. Bishop Tamaron's Visitation of New Mexico, 1760. Historical Society of New Mexico, Albuquerque.

Adams, Eleanor B. and Fray Angelico Chavez (eds. and transls.) 1956. The Missions of New Mexico, 1776: A Description by Fray Francisco Atanasio Dominguez. The University of New Mexico Press, Albuquerque.

Burkholder, Joseph L. 1928. Report of the Chief Engineer: A Plan of Flood Control, Drainage and Irrigation of the Middle Rio Grande Conservancy District. Middle Rio Grande Conservancy District, Albuquerque.

Carlson, Alvar R. 1971. The Rio Arriba: A Geographical Appraisal of the Spanish-american Homeland (Upper Rio Grande Valley, New Mexico). Unpublished Ph.D. dissertation, University of Minnesota, Minneapolis.

Carlson, Alvar R. 1975. Long-Lots in the Rio Arriba. Annals of the Association of American Geographers 65:48-57.

Carter, R.H. 1953. An Historical Study of Floods Prior to 1892 in the Rio Grande Watershed, New Mexico. Unpublished M.A. Thesis, University of New Mexico, Albuquerque.

Clark, Ira G. 1987. Water in New Mexico: A History of its Management and Use. University of New Mexico Press, Albuquerque.

Conkling, Harold, and Erdman Debler 1919. Water Supply for the Possible Development of Irrigation and Drainage Projects on the Rio Grande River above El Paso, Texas. Ms. on file, Bureau of Reclamation, District Office, Albuquerque.

Cordell, Linda S. 1979. Cultural Resources Overview: Middle Rio Grande Valley, New Mexico. Bureau of Land Management and USDA Forest Service, Albuquerque. Government Printing Office, Washington, D.C.

Dortignac, E.J. 1963. Rio Puerco: Abused basin. In Aridity and Man, edited by C. Hodge and P.C. Duisberg, pp. 507-515. American Association for the Advancement of Science Publication No. 74. Washington, D.C.

Earls, Amy Clair 1985. The Organization of Piro Pueblo Subsistence: A.D. 1300 to 1680. Unpublished Ph.D. Dissertation, University of New Mexico, Albuquerque.

Ellis, Florence Hawley 1970. Irrigation and Water Works in the Rio Grande Valley. Paper presented at the Water Control Systems Symposium, organized by J.C. Kelley. 58th Annual Pecos Conference, Santa Fe, New Mexico. Ms. on file, Laboratory of Anthropology, Museum of New Mexico, Santa Fe.

Espinosa, J. Manuel 1940. First Expedition of De Vargas with New Mexico. University of New Mexico Press, Albuquerque.

Espinosa, J. Manuel 1942. Crusaders of the Rio Grande. Institute of Jesuit History, Chicago, Illinois.

Follett, W.W. 1896. A Study of the Use of Water for Irrigation on the Rio Grande del Norte above Fort Quitman, Texas. Proceedings of the International Boundary Commission. Government Printing Office, Washington, D.C.

Gault, Homer J. 1923. Report on the Middle Rio Grande Reclamation Project, New Mexico. U.S. Reclamation Service, Denver, Colorado. Ms. on file in the Records of the Elephant Butte Irrigation District, Rio Grande Historical Collection, New Mexico State University, Las Cruces.

Gregg, Josiah 1954. Commerce of the Plains (originally published in 1849 by H.G. Langley, New York). Bobbs-Merrill, New York.

Hackett, Charles W. (ed.) 1942. Revolt of the Pueblo Indians of New Mexico and Otermin's Attempted Reconquest, 1680-1682. 2 vols. University of New Mexico Press, Albuquerque.

Hammond, George P., and Agapito Rey 1940. Narratives of the Coronado Expedition, 1540-1542. University of New Mexico Press, Albuquerque.

Hammond, George P., and Agapito Rey 1953. Don Juan de Oñate, Colonizer of New Mexico, 1598-1628. 2 vols. University of New Mexico Press, Albuquerque.

Hammond, George P., and Agapito Rey 1966. The Rediscovery of New Mexico, 1580-1594. University of New Mexico Press, Albuquerque.

Harper, Allan G., Andrew R. Cordova, and Kalervo Oberg 1943. Man and Resources in the Middle Rio Grande Valley. University of New Mexico Press, Albuquerque.

Harroun, P.G. 1898. Present Condition of Irrigation and Water Supply in New Mexico. Commission on Irrigation and Water Rights of New Mexico, Santa Fe. Ms. on file, State Engineer's Office, Santa Fe.

Hedke, C.R. 1925. Report on the Irrigation Development and Water Supply in the Middle Erio Grande Valley, New Mexico. Rio Grande Valley Survey Commission, Albuquerque. Ms. on file, Middle Rio Grande Conservancy District Office, Albuquerque.

Hodges, Paul V. 1938. Report on Irrigation and Water Supply of the Pueblos of New Mexico in the Rio Grande Basin. United Pueblos Agency, Albuquerque. ms. on file, Bureau of Reclamation, District Office, Albuquerque.

John, Elizabeth A.H. 1975. Storms Brewed in Other Men's Worlds: The Confrontation of Indians, Spanish and French in the Southwest, 1540-1795. Texas A & M Press, College Station.

Linford, Dee 1956. Water Resources of New Mexico. New Mexico State Engineer's Office and interstate Stream Commission. Ms. on file, New Mexico State Engineer's Office, Santa Fe.

Morfi, Agustin de 1932. Geographical Description of New Mexico, 1782. In A.B. Thomas (ed. and transl.) Forgotten Frontiers, A Study of the Spanish Indian Policy of Don Juan Bautista de Anza, Governor of New Mexico, 1777-1787, pp. 87-114. University of Oklahoma Press, Norman.

National Resources Committee 1938. Regional Planning, Part IV: The Rio Grande Joint Investigation in the Upper Rio Grande Basin in Colorado, New Mexico and Texas, 1936-1937. Government Printing Office, Washington, D.C.

Ressler, John Q. 1968. Indian and Spanish Water Control on New Spain's Northwest Frontier. Journal of the West 7:10-17.

Riley, Caroll L. 1987. The Frontier People: The Greater Southwest in the Protohistoric Period. University of New Mexico Press, Albuquerque.

Simmons, Marc 1969. Settlement Patterns and Village Plans in Colonial New Mexico. Journal of the West 8:7-19.

Simmons, Marc 1972. Spanish Irrigation Practices in New Mexico. New Mexico Historical Review 47:135-150.

Stewart, H.C. 1936. Measures of Erosion Control and Soil Conservation Practices by Type-of-Farming Subregion: Agronomy, Animal Husbandry, Agricultural Economics, Horticulture and Irrigation. USDA Soil Conservation Service, Region 8, Albuquerque.

Van Ness, John R. 1979. Hispanic Village Organization in Northern New Mexico. In The Survival of Spanish American Villages, edited by Paul Kutshce, pp. 21-44. Colorado College, Colorado Springs.

Westphall, Victor 1983. Mercedes Reales: Hispanic Land Grants of the Upper Rio Grande Region. University of New Mexico Press, Albuquerque.

Wortman, Richard A. 1971. Environmental Implications of Surface Water Resource Development in the Middle Rio Grande Drainage, New Mexico. Unpublished M.A. Thesis, University of New Mexico, Albuquerque.

Wozniak, Frank E. 1987. Irrigation in the Rio Grande Valley, New Mexico: A Study of the Development of Irrigation Systems before 1945. Southwest Regional Office, Bureau of Reclamation, Amarillo and New Mexico State Historic Preservation Division, Santa Fe.

Yeo, Herbert W. 1910. Report on Hydrographic and Irrigation Conditions in the Rio Grande Valley, New Mexico. U.S. Reclamation Service, El Paso. Ms. on file, Rio Grande Historical Collection 94, Branson Library, New Mexico State University, Las Cruces.

Yeo, Herbert W. 1929. Report on Investigations in the Rio Grande Basin in Texas above Fort Quitman and in New Mexico during 1907, 1920, and 1928. Office of the State Engineer, Santa Fe.

Yeo, Herbert W. 1943. Data on Rio Grande Floods Prior to 1943. U.S. Army Corps of Engineers, Albuquerque District. Ms. on file, Bureau of Reclamation, District Office, El Paso.

A preliminary riparian/wetland vegetation community classification of the Upper and Middle Rio Grande watersheds in New Mexico

Paula Durkin[1], Esteban Muldavin[2], Mike Bradley[3], and Stacey E. Carr[4]

Abstract.—The riparian/wetland vegetation communities of the upper and middle Rio Grande watersheds in New Mexico were surveyed in 1992 through 1994. The communities are hierarchically classified in terms of species composition and vegetation structure. The resulting Community Types are related to soil conditions, hydrological regime, and temporal dynamics. The classification is part of a comprehensive effort to develop a systematic understanding across the state of the diversity of riparian/wetland communities and how they are influenced by specific hydrologic, edaphic and climatic environments. An overview of the classification is presented with an emphasis on the middle Rio Grande watershed. The floristic composition, structure, environmental relationships, and successional trends of example communities are briefly described. Also discussed is the classification process which leads to the initial inventory and mapping of resources, and the identification of high quality sites.

INTRODUCTION

In New Mexico and elsewhere in the Southwest riparian areas are the conspicuous narrow belts of vegetation along ephemeral, intermittent, and perennial streams that occupy less than one percent of the western landscape (Knopf et al. 1988). Despite their limited extent, these areas support some of the greatest diversity of plant and animal communities in the region (Pase and Layser 1977, Hink and Ohmart 1984, Siegel and Brock 1990, Howe and Knopf 1991, Crawford et al. 1993, Durkin et al. 1995). The geographic extent of native riparian/wetland ecosystems is declining rapidly along many of the major river systems in the Southwest (Carothers 1977, Fenner et al. 1985, Howe and Knopf 1991, Crawford et al. 1993, Stromberg et al. 1993, Busch and Scott 1995, Durkin et al. 1995, Roelle and Hagenbuck 1995). It is thus considered to be a highly threatened ecosystem. In response to this decline in resource value the state of New Mexico, through the Environment Department, has initiated the development of a Wetlands Protection Plan for this ecosystem following the guidelines of the National Wetlands Policy Forum. The primary goals of this plan are inventory and assessment of wetland resources, the identification of wetlands protection mechanisms and the development of strategies for implementation of the plan.

To meet the first goal of inventory and assessment, a classification of riparian/wetland vegetation communities of the state was initiated to aid in inventory and assessment. We present the

[1] Graduate student, University of New Mexico, Department of Biology and research associate for the New Mexico Natural Heritage Program, Albuquerque, NM.

[2] Senior Research Scientist, New Mexico Natural Heritage Program, University of New Mexico, Department of Biology, Albuquerque, NM.

[3] Assistant Community Ecologist, New Mexico Natural Heritage Program, University of New Mexico, Department of Biology, Albuquerque, NM.

[4] Intern for The Nature Conservancy at the New Mexico Natural Heritage Program, University of New Mexico, Department of Biology, Albuquerque, NM.

hierarchical structure of this classification and list the vegetation communities we have identified for the upper and middle Rio Grande watershed. We also provide selected examples of typical communities showing their position in the landscape in relation to one another, their associated soils, as well as the hydrological regime and vegetation dynamics. We then discuss how the classification process has been useful in identifying and assessing the processes, dynamics and quality of riparian ecosystems.

STUDY AREA

The study area includes the "upper" and "middle" watersheds of the Rio Grande in New Mexico (Fig. 1). The upper Rio Grande stretches from the Colorado border to Cochiti Dam. The major tributary is the Chama River, along with several smaller ones such as Embudo Creek, Red River, and the Nambe River. The middle Rio Grande stretches from Cochiti Lake south to Elephant Butte Reservoir. Its major tributaries include the Rio Puerco, Rio San Jose and Rio Salado. Important smaller streams include the Jemez River, Santa Fe River and Galisteo Creek to the north, and the Alamosa, Palomas and Las Animas Creeks to the south.

Precipitation patterns vary, but the primary pattern is that of predominantly late-summer rains (60-80%) derived from the Gulfs of Mexico and California. However, with respect to runoff, while summer storms contribute significantly to late-summer and fall discharges, peak runoff usually occurs in late spring (May-June) in response to snowmelt in the surrounding mountains.

Streamflows of the Rio Grande in New Mexico vary not only as a function of local climatic factors and environment, but also as a result of stream diversions and impoundments. Regulated streamflow on the Rio Grande begins near the headwaters at the Rio Grande Reservoir in southern Colorado, but the impact on flows in New Mexico is minor. Irrigation drawdown in the San Luis Valley in Colorado can have impacts on mid- and late-summer flows. Despite these upper watershed impoundments and diversions, the Rio Grande from the Colorado border south for 50 miles through the Rio Grande Gorge is still considered

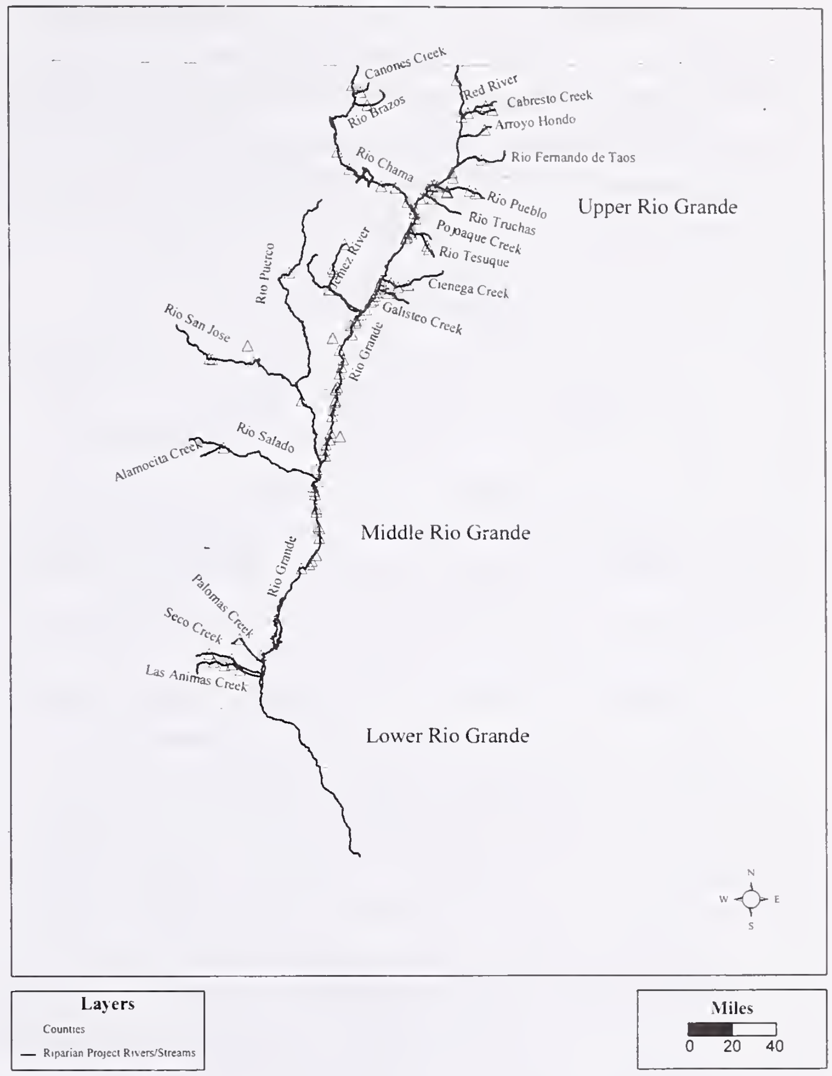


Figure 1. Distribution of riparian/wetland sites assessed and the tributary reaches sampled in the Rio Grande watershed, New Mexico.

free flowing, and is protected by the Wild and Scenic Rivers Act of 1968 (Bullard and Wells 1992). South of the Gorge, the Rio Grande opens up into a wide floodplain at Velarde, and down through Española. Here, significant irrigation diversions occur, and channel controls have been implemented for flood and erosion control, and water delivery.

In the upper Rio Grande several tributary basins have also been altered. The Rio Chama has three major water impoundments (Abiquiu, Heron and El Vado) and, via transmountain tunnels, receives water from the San Juan River as well. Other smaller tributaries, for example Embudo Creek, are contained by small levees bordering the channel, and have water diverted into small irrigation systems (acequias).

The middle Rio Grande runs through the middle basin from Cochiti Lake to Elephant Butte Reservoir (roughly 150 miles). It is intensely managed and altered hydrologically. Nearly every major

tributary, with the exception of the Rio Puerco and Rio Salado, contains a reservoir or diversion dam for flood and sediment control, or irrigation. Water delivery demands and flows are regulated at Cochiti Dam. The channel is periodically dredged and straightened, and banks are rip-rapped to prevent erosion. Additionally, river bars are mowed of their vegetation to maximize water delivery along a 600-foot-wide corridor maintained by a network of flood-control fencing (jetty jacks), and levees. Flows are also diverted into ditches and conveyance channels that drain an area of nearly a quarter million square miles (Hink and Ohmart 1984). Despite these major alterations, the Rio Grande, in certain localities, still overflows its banks within the levees (Crawford et al. 1993).

The middle Rio Grande currently supports one of the most extensive and continuous forested wetlands or "bosques" in the Southwest. The bosque is dominated by Rio Grande cottonwood, along with scattered shrub and herbaceous emergent wetlands of willows and sedges (Hink and Ohmart 1984). Exotics such as Russian olive and salt cedar have become problems, and because of hydrological manipulations the long-term status of these forested wetlands is uncertain (Howe and Knopf 1991, Crawford et al. 1993). The upper Rio Grande and the tributary reaches are considerably less modified and tend to support montane forested wetlands dominated by narrowleaf cottonwoods, and various shrub and herbaceous wetlands. Exotics are less of a problem, and overall site conditions are better.

METHODS

Site selection and field sampling

Vegetation sampling was designed to characterize the communities throughout the study area and to evaluate their relationship to the hydrological regime and soils. Using aerial photography and reconnaissance flights along each of the major reaches of the Rio Grande and its tributaries identified above, potential sites for field sampling were categorized by gross vegetation structure, species composition, size and condition. National Wetlands Inventory maps were consulted to confirm gross vegetation type (NWI 1984). Sites dominated by both native and exotic vegetation such as saltcedar or Russian olive were considered. Final sampling site selection was determined by ground reconnaissance. The final sample set was structured to maximize geographic distribution, floristic variation and stand quality. Sites that were drastically altered by human activities such as cultivation, dumping of refuse, livestock holding sites, logging, and mining were not included in the sampling. Site selection was also dependent on finding a relatively homogeneous stand of vegetation 0.1 hectare in size (1,000 meters^2) or larger.

To evaluate potential flows at a site, cross-sections of the channel and the adjacent floodplain were surveyed using either a ground-based level and rod, or by using aerial photographs to photogrammetrically determine elevation and distance along a cross-section(see Durkin et al. 1995 and BOR 1995 for details). Along each cross-section the elevations of current water surface, high-water marks, locations of flood debris and root crown heights for significant riparian species, as well as bank heights of the main channel, and channel substrate character were recorded. Stream gradients along the reach were also measured with a level and rod, and discharges on the day of sampling were measured with an electronic flow meter.

Each cross-section contained one or more vegetation plots and associated soil pits in stands of homogeneous vegetation that represented the typical vegetation community. Within each stand, a 400 m^2 square or rectangular plot was established and canopy cover of all species present estimated. Trees were tallied in two-inch diameter stem-size classes. Height of the canopy was measured, and one or more dominant trees was cored to determine age. Other variables estimated or measured at each site included: elevation, aspect (stream bearing), valley floor width, ground cover, landscape position, hydrologic and geomorphic features, adjacent upland communities, indications of wildlife or domestic livestock utilization, and other disturbances (i.e., flooding, fire, windthrow, logging, etc.). Soil sampling and profile descriptions followed guidelines established by the Soil Conservation Service (SCS 1991). For each horizon, bulk samples for pH and salinity determinations were also taken.

Analysis

Hydraulic analysis was performed on each cross-section resulting in estimated flows at designated stage heights. The analysis of simpler and smaller streams was done with XSPRO (Grant et al. 1992). Modeled flows were calibrated from discharge measurements for the date of sampling, or from nearby U.S.G.S. gauges. Complex modeling of the larger Rio Grande was accomplished in cooperation with the Bureau of Reclamation and their STARS program which estimates flood stage height and discharge by comparing the hydraulic gradients of two or more cross-sections (backwater calculation). Water surface stages are interactively computed for all cross-sections until they correspond (BOR 1995).

Return intervals for flows at various stages on the cross-sections was determined using the recurrence probabilities calculated at stream gauges by Waltemeyer (1986). For the cross-sections located on smaller tributary basins without stream gauging stations, recurrence intervals were calculated using Waltemeyer's (1986) linear regression equations based on drainage basin size and elevation.

As a corollary to recurrence interval, the ratio of the cross-sectional area of the floodplain to the cross-sectional area of the channel at bankfull height was calculated. Each vegetation plot located on a cross-section has a recurrence interval associated with it along with cross-sectional ratios and actual cubic feet per second (cfs) discharges necessary to flood the site.

Soils were classified to the family level of Soil Taxonomy (Soil Survey Staff 1992). Soils were also ranked in terms of wetness based on Great Group and Family characteristics. Percentages of plant available water based on soil texture were estimated for the moisture control section of the soil profile (Donahue et al. 1983). Depths to gleying and redox features were also determined.

The vegetation community classification was developed using agglomerative cluster analysis. Euclidean distance and Ward's Method was used as an initial organizational tool to define the riparian/wetland community types. The program SYNTAX IV (Podani 1990) was used to generate a dendrogram of hierarchical groupings of plots with similar vegetation associates. Plots were then sorted using synthesis stand tables into final vegetation community types following procedures outlined in Mueller-Dombois and Ellenberg (1974). Hydrological, soil and other site characteristics were then correlated to community types.

RESULTS

The classification system

The classification system is organized in a multi-level hierarchical and open-ended system based primarily on the existing natural vegetation. The system draws upon Cowardin's (1979) classification of wetlands and deepwater habitats of the United States; Brown, Lowe and Pase's (1979) classification of biotic communities of the Southwest; and UNESCO's physiognomic-ecological classification of plant formations of the earth (Mueller-Dombois and Ellenberg 1974, Driscoll et al. 1984, Bourgeron and Engelking 1994). The UNESCO system is currently used by Natural Heritage Programs throughout the United States as a basis for regional, national and international comparisons. The classification of Cowardin et al. (1979) was adopted by the U.S. Fish and Wildlife Service for use in its National Wetland Inventory.

Initially, all riparian/wetland communities are considered part of the Palustrine System as defined by Cowardin et al. (1979). There are seven hierarchical levels to the classification structure:

1. **Class** — The major physiognomic type based on dominant growth form and cover; similar to Class of Cowardin et al. (1979) and UNESCO (Driscoll et al. 1984);
2. **Zone** — Moisture and temperature-defined sub-classes; similar to Brown, Lowe and Pase's (1979) Climatic Zone and SubClass and Group in part, of UNESCO;
3. **Regional Biome** — Biogeographically related Series Groups; similar to Brown, Lowe and Pase's (1979) Biome;
4. **Series Group** — The dominant plant communities within the same biome, zone, and class related by equivalent sets of morphological, environmental or floristically related series; commonly equivalent to the Cowardin et al.

(1979) Sub-class and UNESCO Formation (Driscoll et al. 1984);

5. **Series** — Sets of Community Types related by at least a single common dominant; equivalent to the primary Dominance Types of Cowardin et al. (1979) and patterned after the Series of Daubenmire (1968), and the Alliance of Braun-Blanquet (1965) and Bourgeron and Engelking (1994);
6. **Community Type** — Fundamental repeated assemblages of species; synonymous with plant association of Braun-Blanquet (1965) and Bourgeron and Engelking (1994); somewhat equivalent to secondary Dominance Types of Cowardin et al. (1979);
7. **Phase** — Floristic variants of Community Types; synonymous with sub-association of Braun-Blanquet (1965); the term Typic refers to the modal species composition of the Community Type.

Upper and Middle Rio Grande Basin riparian/wetland communities

A preliminary classification of riparian/wetland vegetation communities of the upper and middle Rio Grande Basin is presented in Table 1. It is based on data from 52 cross-sections, and 109 vegetation plots and soil pits distributed throughout the basin (Figure 1). Communities are divided into three main Classes — forested, scrub-shrub and persistent emergent herbaceous riparian/wetlands. Within each Class there can be either Cold Temperate or Warm Temperate Zones (Level II), followed by Regional Biomes such as Rocky Mountain Montane, Rio Grande/Great Plains or Southwest (Level III). Level IV's are commonly defined as either needle-leaved evergreen series groups, or broad-leaved deciduous series groups. At the lowest levels of the classification, we identified 20 Series and 58 community types within those series.

Table 1. A preliminary riparian/wetland vegetation community classification of New Mexico for the upper and middle Rio Grande watershed. The classification is hierarchically arranged within the Palustrine System into Class (level I), Zone (level II), Regional Biome (level III), Series Group (level IV), Series (level V) and Community Type (CT; level VI). Organization of the classification system follows Cowardin's (1979) classification system with modifications based on NMNHP's statewide classification (see text). The Series Group, level (IV), is parenthetically cross referenced to the UNESCO classification system (Driscoll et al. 1984). Community Types are identified by their common name, scientific nomenclature, and six- or seven-letter acronym.

PALUSTRINE SYSTEM—RIPARIAN/WETLAND VEGETATION

I. FORESTED WETLANDS CLASS - FORESTS AND WOODLANDS

II. COLD TEMPERATE FORESTED RIPARIAN/WETLANDS

III. ROCKY MOUNTAIN MONTANE FORESTS

IV. NEEDLE-LEAVED EVERGREEN SERIES GROUP (closed forests, cold temperate, evergreen)

V. BLUE SPRUCE *(PICEA PUNGENS)* SERIES

1. Blue Spruce—Thinleaf Alder CT *(Picea pungens—Alnus incana;* PICPUN—ALNINCT*)*

IV. BROAD-LEAVED DECIDUOUS SERIES GROUP (closed forests, cold temperate, deciduous with evergreens)

V. THINLEAF ALDER *(ALNUS INCANA)* SERIES

1. Thinleaf Alder/Bluestem Willow CT (*Alnus incana/Salix irrorata*; ALNINCT/SALIRR)

V. NARROWLEAF COTTONWOOD (*POPULUS ANGUSTIFOLIA*) SERIES

1. Narrowleaf Cottonwood—Thinleaf Alder CT (*Populus angustifolia—Alnus incana*; POPANG—ALNINCT)
2. Narrowleaf Cottonwood—Arizona Alder CT (*Populus angustifolia—Alnus oblongifolia*; POPANG—ALNOBL)
3. Narrowleaf Cottonwood—Rocky Mountain Juniper CT *(Populus angustifolia—Juniperus scopulorum*; POPANG—JUNSCO)
4. Narrowleaf Cottonwood/New Mexico Olive CT (*Populus angustifolia/Forestiera pubescens* CT; POPANG/FORPUBP)
5. Narrowleaf Cottonwood/Coyote Willow CT (*Populus angustifolia/Salix exigua*; POPANG/SALEXI)
6. Narrowleaf Cottonwood/Bluestem Willow CT (*Populus angustifolia/Salix irrorata*; POPANG/SALIRR)
7. Narrowleaf Cottonwood/Kentucky Bluegrass CT *(Populus angustifolia/Poa pratensis*; POPANG/POAPRA)

(Cont'd.)

Table 1. Continued

III. SOUTHWEST MONTANE FORESTS
IV. BROAD-LEAVED DECIDUOUS SERIES GROUP (closed forests, cold temperate, deciduous with evergreens)

V. ARIZONA ALDER (*ALNUS OBLONGIFOLIA*) SERIES
1. Arizona Alder—Goodding's Willow CT (*Alnus oblongifolia—Salix gooddingii*; ALNOBL—SALGOO)
2. Arizona Alder/Seepwillow CT (*Alnus oblongifolia/Baccharis salicifolia*; ALNOBL/BACSAL)

III. RIO GRANDE/GREAT PLAINS FORESTS
IV. BROAD-LEAVED DECIDUOUS SERIES GROUP (woodlands, cold temperate, deciduous with microphyllous shrublands or thickets)

V. RIO GRANDE COTTONWOOD (*POPULUS DELTOIDES*) SERIES
1. Rio Grande Cottonwood—Russian Olive CT (*Populus deltoides—Elaeagnus angustifolia*; POPDELW—ELAANG)
2. Rio Grande Cottonwood—Oneseed Juniper CT (*Populus deltoides—Juniperus monosperma;* POPDELW—JUNMON)
3. Rio Grande Cottonwood—Saltcedar CT (*Populus deltoides—Tamarix chinensis*; POPDELW—TAMCHI)
4. Rio Grande Cottonwood/New Mexico Olive CT (*Populus deltoides/Forestiera pubescens*; POPDELW/FORPUBP)
5. Rio Grande Cottonwood/Coyote Willow CT (*Populus deltoides/Salix exigua*; POPDELW/SALEXI)
6. Rio Grande Cottonwood/Water Sedge CT (*Populus deltoides/Carex aquatilis*; POPDELW/CARAQU)
7. Rio Grande Cottonwood/Smooth Horsetail CT (*Populus deltoides/Equisetum laevigatum*; POPDELW/EQULAE)
8. Rio Grande Cottonwood/Kentucky Bluegrass CT (*Populus deltoides/Poa pratensis*; POPDELW/POAPRA)
9. Rio Grande Cottonwood/Sparse CT (*Populus deltoides*/Sparse; POPDELW/SPARSE)

V. RUSSIAN OLIVE (*ELAEAGNUS ANGUSTIFOLIA*) SERIES
1. Russian Olive—Saltcedar CT (*Elaeagnus angustifolia—Tamarix chinensis*; ELAANG—TAMCHI)

IV. NEEDLE-LEAVED DECIDUOUS SERIES GROUP (cold deciduous microphyllous thickets)

V. SALTCEDAR (*TAMARIX CHINENSIS*) SERIES
1. Saltcedar/Coyote Willow CT (*Tamarix chinensis/Salix exigua*; TAMCHI/SALEXI)
2. Saltcedar/Sparse CT (*Tamarix chinensis*/Sparse; TAMCHI/SPARSE)

II. WARM TEMPERATE FORESTED RIPARIAN/WETLANDS
III. SOUTHWEST LOWLAND FORESTS
IV. BROAD-LEAVED DECIDUOUS SERIES GROUP (closed forests, warm temperate, deciduous with evergreens, or microphyllous shrublands or thickets)

V. NETLEAF HACKBERRY (*CELTIS LAEVIGATA*) SERIES
1. Netleaf Hackberry/Skunkbush Sumac CT (*Celtis laevigata/Rhus trilobata*; CELLAER/RHUTRIT)

V. ARIZONA WALNUT (*JUGLANS MAJOR*) SERIES
1. Arizona Walnut/Sideoats Grama CT (*Juglans major/Bouteloua curtipendula*; JUGMAJ/BOUCUR)

V. ARIZONA SYCAMORE (*PLATANUS WRIGHTII*) SERIES
1. Arizona Sycamore—Arizona Alder CT (*Platanus wrightii—Alnus oblongifolia*; PLAWRI—ALNOBL)
2. Arizona Sycamore/Seepwillow CT (*Platanus wrightii/Baccharis salicifolia*; PLAWRI/BACSAL)
3. Arizona Sycamore/Sideoats Grama CT (*Platanus wrightii/Bouteloua curtipendula*; PLAWRI/BOUCUR)
4. Arizona Sycamore/Sparse CT (*Platanus wrightii*/Sparse; PLAWRI/SPARSE)

V. FREMONT'S COTTONWOOD (*POPULUS FREMONTII*) SERIES
1. Fremont's Cottonwood—Velvet Ash CT (*Populus fremontii—Fraxinus velutina*; POPFRE—FRAVEL)
2. Fremont's Cottonwood—Goodding's Willow CT (*Populus fremontii—Salix gooddingii*; POPFRE—SALGOO)
3. Fremont's Cottonwood/Yerba Mansa CT (*Populus fremontii/Anemopsis californica*; POPFRE/ANECAL)

I. SCRUB-SHRUB WETLANDS CLASS - SHRUBLANDS
II. COLD TEMPERATE SCRUB-SHRUB RIPARIAN/WETLANDS
III. ROCKY MOUNTAIN MONTANE SHRUBLANDS
IV. BROAD-LEAVED DECIDUOUS SERIES GROUP (scrub, cold temperate, deciduous shrublands or thickets)

(Cont'd.)

Table 1. Continued

V. BLUESTEM WILLOW *(SALIX IRRORATA)* SERIES
1. Bluestem Willow—Coyote Willow CT *(Salix irrorata—Salix exigua*; SALIRR—SALEXI)
2. Bluestem Willow/Sparse CT *(Salix irrorata*/Sparse; SALIRR/SPARSE)

III. RIO GRANDE/GREAT PLAINS SHRUBLANDS
IV. BROAD-LEAVED DECIDUOUS SERIES GROUP (scrub, cold temperate, deciduous shrublands or thickets)

V. COYOTE WILLOW *(SALIX EXIGUA)* SERIES
1. Coyote Willow—Rubber Rabbitbrush CT *(Salix exigua—Chrysothamnus nauseosus*; SALEXI—CHRNAU)
2. Coyote Willow/Redtop CT *(Salix exigua/Agrostis gigantea*; SALEXI/AGRGIG)
3. Coyote Willow/Water Sedge CT *(Salix exigua/Carex aquatilis*; SALEXI/CARAQU)
4. Coyote Willow/Woolly Sedge CT *(Salix exigua/Carex lanuginosa*; SALEXI/CARLAN)
5. Coyote Willow/Saltgrass CT *(Salix exigua/Distichlis spicata*; SALEXI/DISSPI)
6. Coyote Willow/Common Spikerush CT (*Salix exigua/Eleocharis palustris*; SALEXI/ELEPAL)
7. Coyote Willow/False Quackgrass CT *(Salix exigua/Elymus* x *pseudorepens*; SALEXI/ELYPSE)
8. Coyote Willow/Smooth Horsetail CT *(Salix exigua/Equisetum laevigatum*; SALEXI/EQULAE)
9. Coyote Willow/Baltic Rush CT *(Salix exigua/Juncus balticus*; SALEXI/JUNBAL)
10. Coyote Willow/American Bulrush CT (*Salix exigua/Scirpus americanus*; SALEXI/SCIAME)

II. WARM TEMPERATE SCRUB-SHRUB RIPARIAN/WETLANDS
III. SOUTHWEST LOWLAND SHRUBLANDS
IV. BROAD-LEAVED DECIDUOUS SERIES GROUP (scrub, cold temperate, deciduous shrublands or thickets)

V. SEEPWILLOW *(BACCHARIS SALICIFOLIA)* SERIES
1. Seepwillow/Prairie Wedgescale CT *(Baccharis salicifolia/Sphenopholis obtusata*; BACSAL/SPHOBT)

V. COYOTE WILLOW *(SALIX EXIGUA)* SERIES
1. Coyote Willow—Seepwillow CT *(Salix exigua—Baccharis salicifolia*; SALEXI—BACSAL)
2. Coyote Willow/Yerba Mansa CT (*Salix exigua*/Anemopsis californica; SALEXI/ANECAL)
3. Coyote Willow/Sparse CT *(Salix exigua*/Sparse; SALEXI/SPARSE)

I. PERSISTENT-EMERGENT WETLANDS CLASS - HERBACEOUS RIPARIAN/WETLANDS
II. COLD TEMPERATE PERSISTENT-EMERGENT RIPARIAN/WETLANDS
III. ROCKY MOUNTAIN MONTANE HERBACEOUS RIPARIAN/WETLANDS
IV. PERSISTENT SERIES GROUP (terrestrial herbaceous communities, sedge swamps or temperate reed swamps on river banks)

V. BALTIC RUSH *(JUNCUS BALTICUS)* SERIES
1. Baltic Rush—Nebraska Sedge CT *(Juncus balticus—Carex nebrascensis*; JUNBAL—CARNEB)
2. Baltic Rush—Common Spikerush CT *(Juncus balticus—Eleocharis palustris*; JUNBAL—ELEPAL)
3. Baltic Rush/Smooth Horsetail CT *(Juncus balticus/Equisetum laevigatum*; JUNBAL/EQULAE)

V. AMERICAN BULRUSH *(SCIRPUS AMERICANUS)* SERIES
1. American Bulrush—Common Spikerush CT *(Scirpus americanus—Eleocharis palustris*; SCIAME—ELEPAL)
2. American Bulrush/Smooth Horsetail CT *(Scirpus americanus/Equisetum laevigatum*; SCIAME/EQULAE)

III. SOUTHWEST LOWLAND HERBACEOUS RIPARIAN/WETLANDS
IV. PERSISTENT SERIES GROUP (terrestrial herbaceous communities, sedge swamps or temperate reed swamps on river banks)

V. WATER SEDGE (*CAREX AQUATILIS*) SERIES
1. Water Sedge/Smooth Horsetail CT *(Carex aquatilis/Equisetum laevigatum*; CARAQU/EQULAE)

V. COMMON SPIKERUSH (*ELEOCHARIS PALUSTRIS*) SERIES
1. Common Spikerush—Rice Cutgrass CT *(Eleocharis palustris—Leersia oryzoides*; ELEPAL—LEEORY)
2. Common Spikerush/Smooth Horsetail CT *(Eleocharis palustris/Equisetum laevigatum*; ELEPAL/EQULAE)

V. BROADLEAF CATTAIL *(TYPHA LATIFOLIA)* SERIES
1. Broadleaf Cattail/American Bulrush CT *(Typha latifolia/Scirpus americanus*; TYPLAT/SCIAME)
2. Broadleaf Cattail/Rice Cutgrass CT *(Typha latifolia/Leersia oryzoides*; TYPLAT/LEEORY)

To elucidate the usefulness of the classification, examples of four representative cross-sections from various parts of the study area are given below. The cross-sections are described in terms of community types, their composition and where those communities lie in the landscape, as well as their soil and hydrological conditions, and implications in terms of community dynamics and sustainability. Three of the examples are from river reaches that are only minimally modified, and a fourth (Corrales Bosque) is from a reach that is highly modified.

Rio Grande/Great Plains riparian/wetlands

The cross-sectional diagram in Figure 2 depicts a typical landscape on the Jemez River, supporting an example of riparian/wetland communities of the Rio Grande/Great Plains. In this reach the hydrological regime is relatively intact with only minor irrigation diversions. The gravelly channel is moderately entrenched and slightly confined by the valley, but definite depositional bars and terraces occur. Depositional bars adjacent to the channel support young stands of the Coyote Willow/Smooth Horsetail community. These sites are currently flooded annually and are potentially good sites for cottonwood regeneration. Hence, the community type can be intermixed with young cottonwood seedlings and saplings. The understory is dominated by grasses and sedges/rushes that are tolerant of water-saturated soils (Aquic or Oxyaquic Ustifluvents), such as Canada wildrye, creeping bentgrass and American spikerush. With recurring flooding, the sites often collect more flood deposits and are built up into higher bars and terraces. Over time the bars build up to the point that they are no longer frequently flooded; cottonwood regeneration stops and the cottonwood forest develops and matures. In this case, the highest terraces, at about eight feet above the channel, and support a mature Rio Grande Cottonwood/New Mexico Olive community. This is probably the most mature type of forest community that can occur here. The sites are only occasionally flooded (5-25 year flood-return intervals), and are relatively stable. Large scouring floods

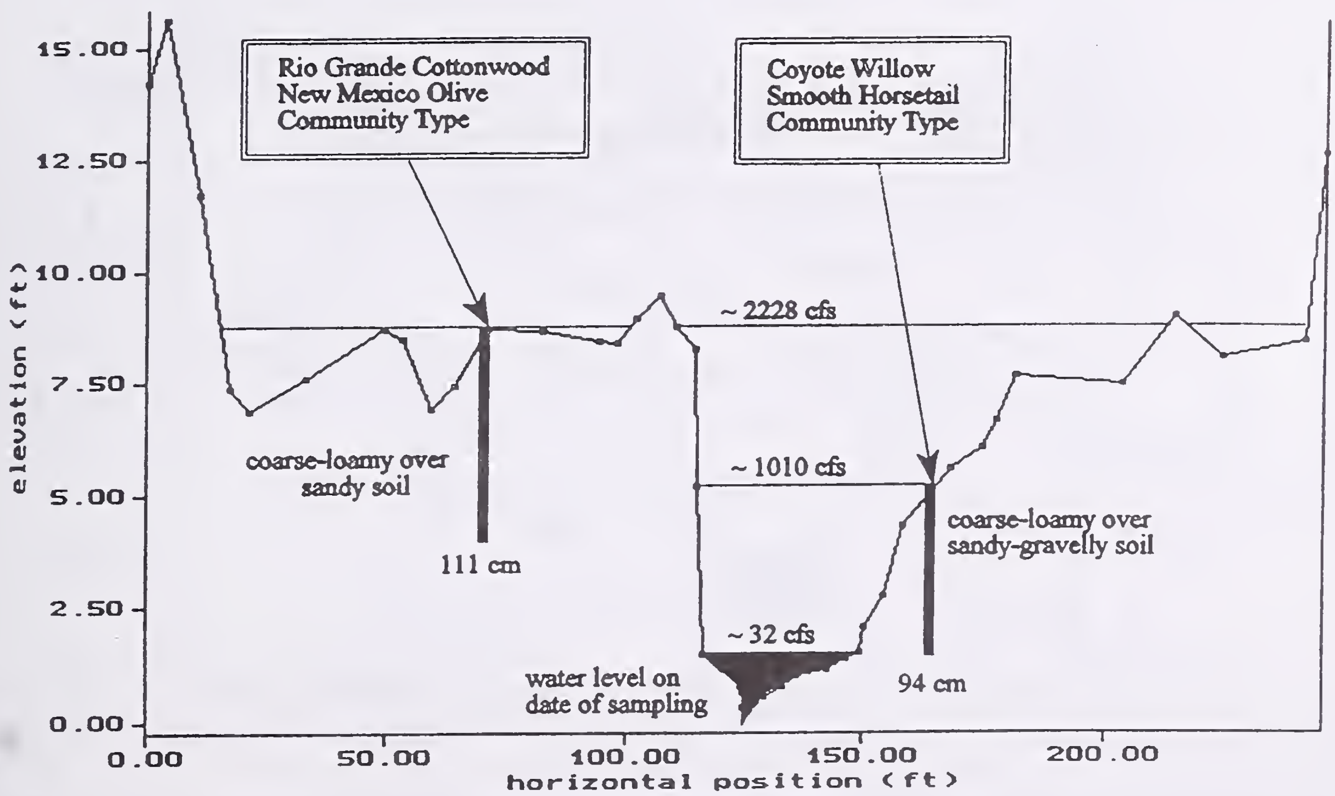


Figure 2. Cross-sectional profile of the Jemez River at the Cañon Site depicting the location of Rio Grande/Great Plains riparian/wetland communities, the predominant soil textures of each type and depths of soil pits (black bar). Also shown is the water level on the day of sampling and the estimated flows required to flood the different communities. For example, an estimated flow of 2228 cubic feet per second (cfs) would recur at 5 year intervals for the Rio Grande Cottonwood/New Mexico Olive Community Type while an estimated flow of 1010 cfs would recur every other year for the Coyote Willow/Smooth Horsetail Community Type.

could still potentially remove the old forest, and restart the cycle. Otherwise, the forest community will probably be sustained on this site until the trees die, either from old age, or if the water table is altered (either naturally, by changing channel configuration, or artificially).

In Figure 3 the cross-sectional diagram also depicts Rio Grande/Great Plains communities along the middle Rio Grande, but on the main stem at Corrales. Here the hydrological regime is highly modified. Flows are regulated at Cochiti Dam and there are numerous upstream irrigation diversions. The floodplain is bounded by levees and conveyance channels, and stabilized with jetty jacks creating a 600-foot-wide channel that is essentially "locked" in place. The bed of the channel is predominantly sandy with mixtures of gravels and silt. At low flows, low-lying depositional bars become exposed and are good sites for cottonwood regeneration. These sites, however, are continually flooded on an annual basis and the cottonwood seedlings are removed, rarely becoming sapling-sized trees, or reaching maturity. Mature stands of Rio Grande Cottonwood/New Mexico Olive communities border the river on high terraces. Unlike the communities on the Jemez cross-section, these stands are even-aged and are often intermixed with exotic trees, commonly Russian olive, salt cedar, and Siberian elm. The communities require more than 10,000 cfs to flood. Restarting the cycle with these flows, however, is beyond the maximum prescribed release that is currently allowed from Cochiti. Hence, the native forest communities will likely be replaced by the exotic trees that do not require flooding for development and maintenance.

Southwest riparian/wetlands

Figure 4 depicts a riparian zone that is different overall from Rio Grande/Great Plains. This landscape is from the southern end of the study area along Palomas Creek. This reach supports Southwest riparian/wetland communities that are closely related to communities of the Gila River basin to the west, and others rivers of Arizona and northern Mexico. The gravelly/cobbly channel is

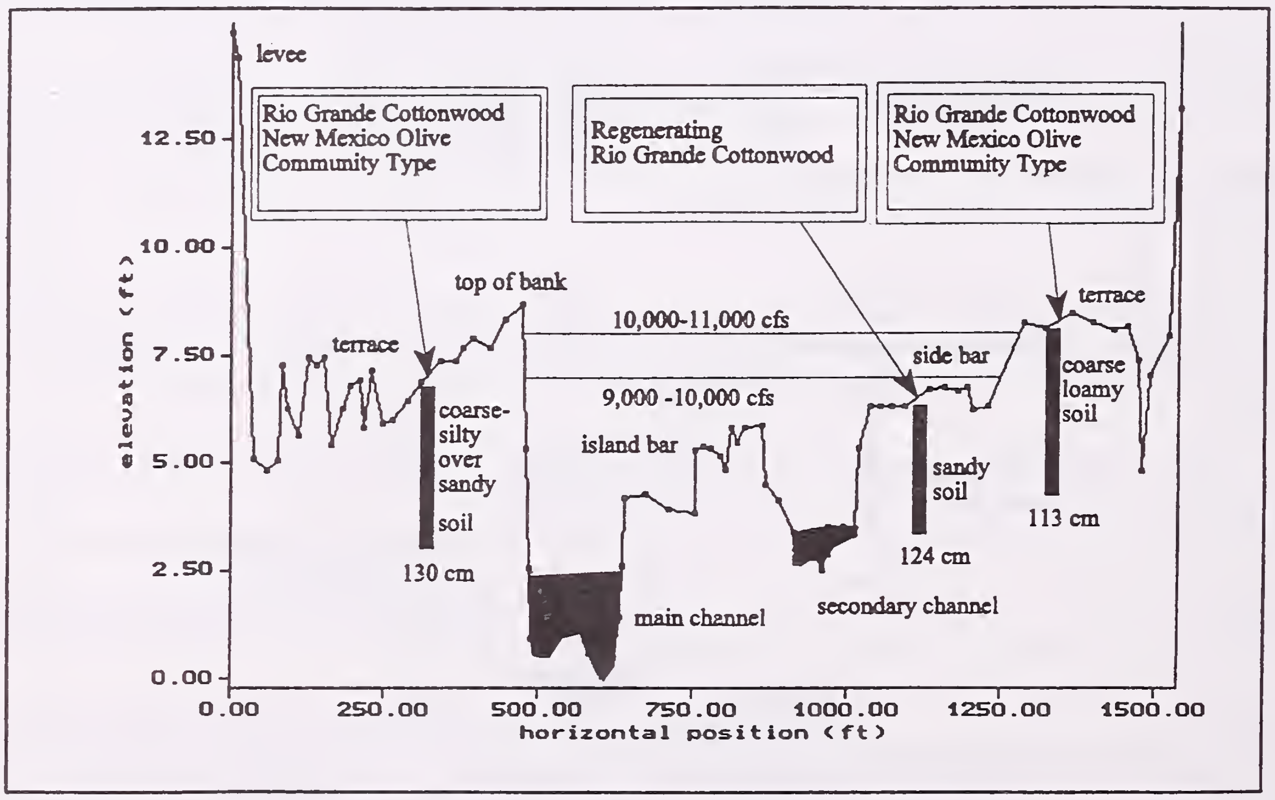


Figure 3. Cross-sectional profile of the middle Rio Grande at the Corrales Bosque Site depicting location of Rio Grande/Great Plains riparian/wetland communities, the predominant soil textures of each type and depths of soil pits (black bar). Along this regulated segment of the river, flows of 10,000-11,000 cubic feet per second (cfs) would nearly reach the highest terraces supporting Rio Grande cottonwood/New Mexico olive communities every 25-100 years, whereas the same flows under unregulated conditions would recur at 2-3 year intervals. The lowest side bars which support sapling-sized cottonwoods would currently require flows of 9,000-10,000 cfs to re-flood these sites and recur at 10-25 year return intervals, while the same unregulated peak flows would recur at approximately 1-2 year return intervals.

moderately entrenched and moderately confined by the valley. It meanders across a narrow floodplain, and overflows the lowest banks at one- to two-year intervals. Within two feet of the active channel herbaceous persistent-emergent vegetation is common beneath an understory of young seepwillow (the Seepwillow/Prairie Wedgescale community type). Reproduction of cottonwoods, willows, and alders occurs in this zone where the soils are frequently saturated. Further away from the channel and slightly higher above it, the Arizona Alder/Seepwillow Community Type develops on drier, coarse sandy-gravelly soils (Aeric Fluvaquents). These soils have either aggraded as a result of continued deposits of sediments during flooding events, or the channel has moved laterally away from the site, or the channel has become slightly incised. Common understory species include sapling-sized Arizona walnut, Goodding's willow, and boxelder, as well as the vine Arizona grape. These sites are only occasionally flooded at 5-25 year intervals and are relatively stable. Beyond two overflow channels and only slightly higher on a terrace, a third community co-dominated by Fremont's cottonwood and Goodding's willow further diversifies the site on slightly different and more developed soils (Oxyaquic Torrifluvents). Hydric indicators are located deeper within the soil profile suggesting that the site is rarely inundated (greater than 25 year return intervals). Sub-canopy trees including Arizona walnut, boxelder and velvet ash may also be present, while understory grasses such as deergrass and alkali muhly may also be well represented. This is a stable forest community that will either be replaced by the sub-canopy trees in the community, or the forest will be reset by large scouring floods.

Rocky Mountain montane

In the upper reaches of the watersheds at higher elevations the Rio Grande/Great Plains and Southwest riparian/wetlands are replaced by Rocky Mountain montane community types. In Figure 5,

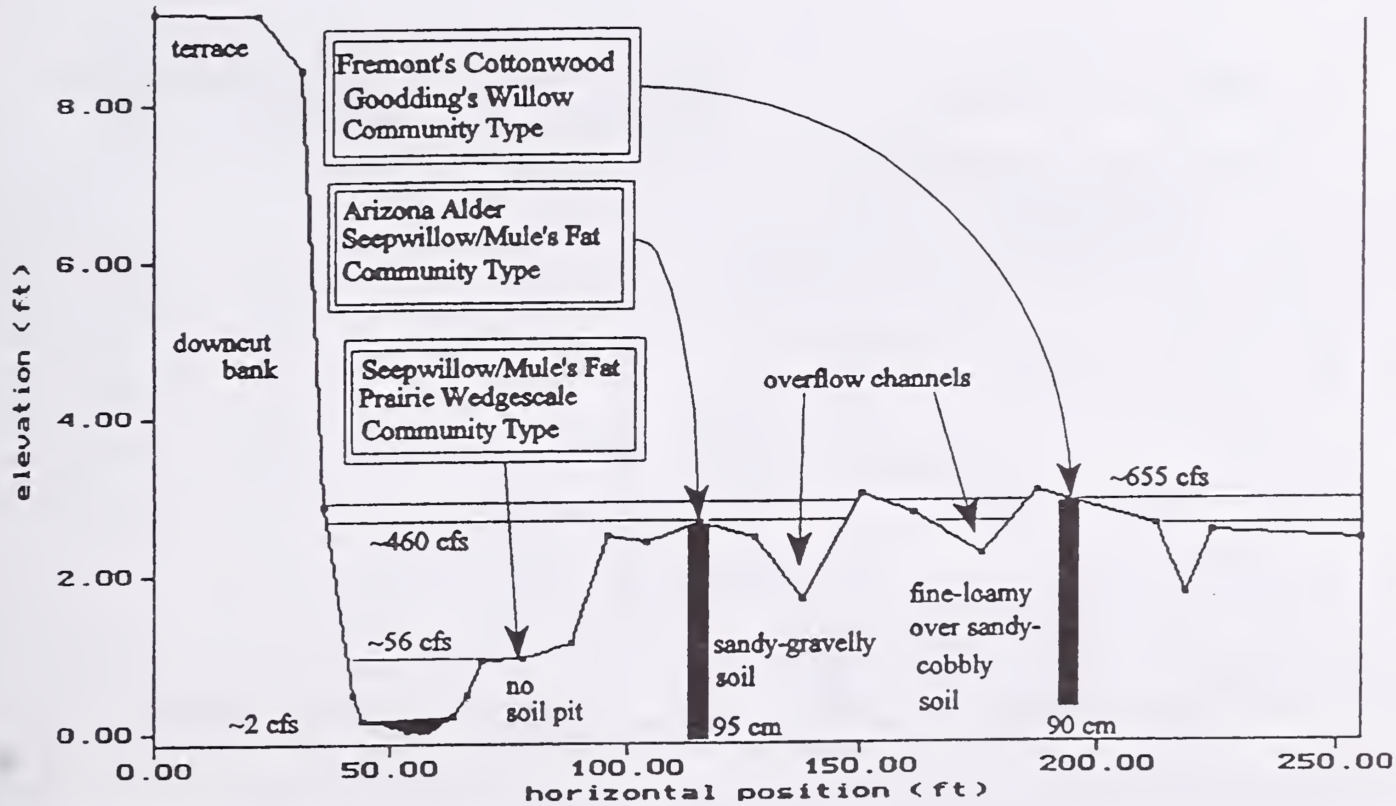


Figure 4. Cross-sectional profile of Palomas Creek depicting the location of three different Southwest riparian/wetland communities, the predominant soil textures of each type and depths of soil pits (black bar). Streamflows on the day of sampling were measured at 2 cubic feet per second. Based on hydraulic analyses flows of approximately 1900 cfs would scour the lowest bars at 5 year intervals , while flows of 50-350 cfs would flood the communities every 2-5 years. Streamflows of approximately 655 cfs would flood the oldest forested community (Fremont's Cottonwood — Goodding's Willow Community Type) at 10-25 year return intervals.

along the Chama River, the dynamics of the communities are driven by a relatively intact hydrological regime that still allows for natural reproduction of obligate riparian/wetland species. At this site the cobbly channel is moderately entrenched and slightly confined by the valley. The lowest depositional bars adjacent to the channel support the Narrowleaf Cottonwood/Coyote Willow Community Type characterized by young cottonwood saplings and seedlings intermixed with willows, and various shrubs and forbs. Stratified layers of vegetation are well developed and the community is species rich. Bearberry honeysuckle and redosier dogwood are common sub-canopy shrub species while forbs and grasses include cutleaf coneflower, cowparsnip, field horsetail, Kentucky bluegrass and meadow fescue. These sites are currently flooded at one- to two-year intervals. Recurring floods over time have built higher terraces between three and six feet above the active channel that support the Narrowleaf Cottonwood—Thinleaf Alder Community Type. Communities closest to the main channel are younger, dense and diverse, while forests further from the channel are older and thinner. With additional floods at up to five year intervals new sites are created for cottonwood regeneration. But as the interval increases, the sites elevated high above the active channel become drier. Soils closest to the channel are fairly well drained Aeric Fluvaquents with water saturation indicators within 75 cm of the surface, while soils furthest from the active channel tend to be coarser Oxyaquic Udifluvents with hydric indicators found deep within the soil profile. On the driest sites cottonwood reproduction ceases and the stands of trees mature and ultimately die. Narrowleaf cottonwood dominated communities, like their lower-elevation relatives require flooding to reset the community. Otherwise, the trees will generally grow old and die and will only be replaced by an occasional root sucker.

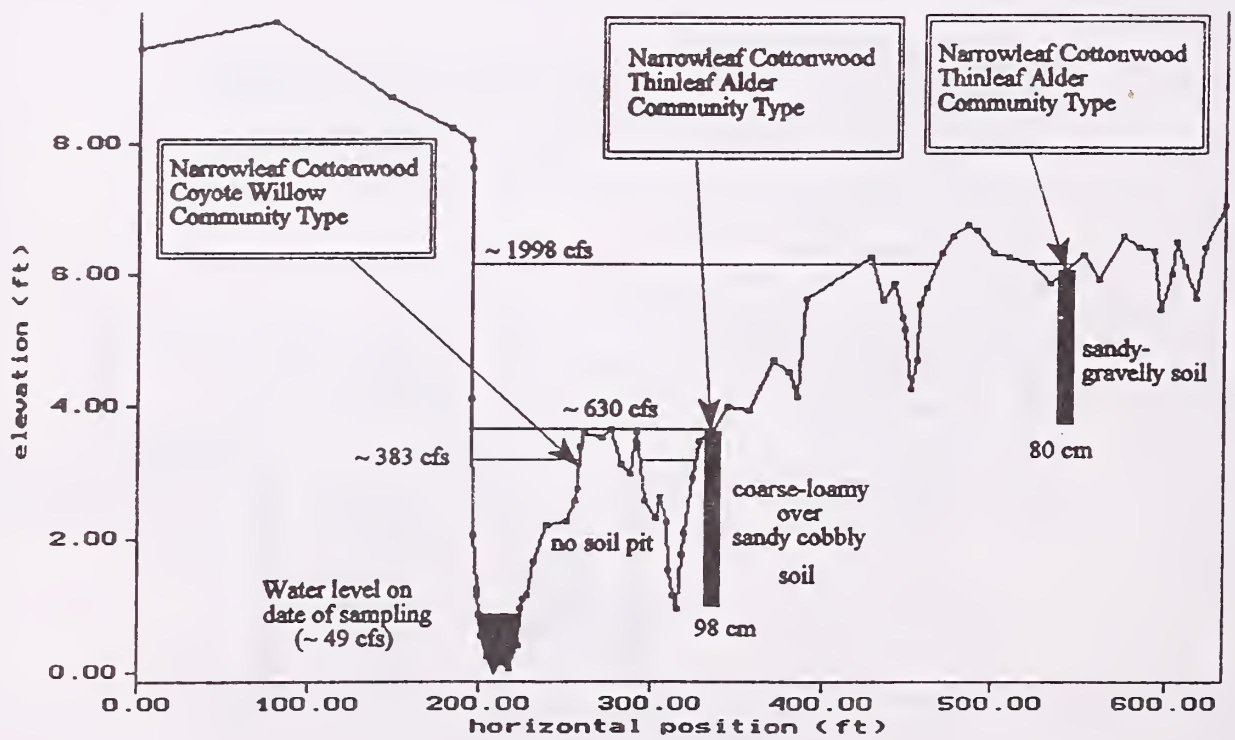


Figure 5. Cross-sectional profile of the Rio Chama near Chama, NM depicting the location of two Montane riparian/wetland communities, the predominant soil textures of each type and depths of soil pits (black bar). Streamflows on the day of sampling were measured at 49 cubic feet per second. The highest terraces which support a mature Narrowleaf cottonwood—Thinleaf alder community would require streamflows of nearly 2000 cubic feet per second to reset the community every 50-100 years, while intermediate-aged stands on lower sites require 630 cfs every 10-25 years. The lowest sites adjacent to the river support Narrowleaf cottonwood/Coyote willow communities and are flooded every 2-10 years with flows of approximately 380 cfs.

DISCUSSION

The high number of community types identified in this study reflects the high diversity of the riparian zones in New Mexico. This classification is based on a limited sample pool, and there will likely be more types that will be identified in the future, particularly with respect to high montane communities, and herbaceous/emergent wetlands in general. The herbaceous emergent and persistent wetlands identified here are under-represented in the landscape as a whole. This may be a reflection of the highly altered condition of the middle Rio Grande, where modification of flows and the channel have resulted in a tree-dominated ecosystem, rather than a more diverse matrix of forests, shrublands and herbaceous communities.

The classification has provided a structure for the analysis and discussion of riparian ecosystem species composition and dynamics. We have identified several naturalized "exotic" community types dominated by Russian olive or salt cedar, and we are further investigating the conditions under which these communities thrive. Through the classification we are developing models for testing concepts on site progression originally outlined by Leonard et al. (1992), both under naturally occurring or artificially controlled systems. This we hope will lead to a greater understanding of the impacts of hydrological manipulations by humans.

We believe the classification developed here will prove useful for comprehensive inventory and quality assessment of New Mexico's riparian/wetland resources. The process itself of developing the classification was important as a tool for initially evaluating the quality of specific occurrences of riparian ecosystems in the state. This in turn has led to the first steps in the protection planning process of identifying high quality, functional or restorable wetlands (see Durkin et al. 1995). The classification process has amplified a definite need to implement riparian/wetland ecosystem protection planning in New Mexico. Of the 109 sites evaluated in the study area, only 18 (16%) were assessed as high quality, i.e., sites lacking significant impacts of hydrological modifications and landuse, and were not greatly impacted by exotic vegetation. Further, many of the best sites were in the higher elevations of more remote tributaries where hydrological modifications were limited. Although this survey was selective for reaches previously known to have extant riparian vegetation, it also points towards a general downward trend of the condition of riparian/wetland communities in New Mexico.

The natural and restorable riparian/wetland ecosystems of New Mexico are an invaluable resource for the state. Their protection enhances not only biological diversity, but also economic stability and environmental quality. With planning, these highly productive ecosystems can be managed in a natural, cost-efficient way that can be compatible with many uses such as livestock grazing, recreation, and even agriculture and urbanization, and still maintain their overall biological diversity. Such an effort will require a systematic, comprehensive inventory based on the classification system and site quality evaluation criteria developed here, along with a program of ongoing research and monitoring to ensure the long term sustainability of these vital resources. Through careful wetlands protection planning and implementation, the so called "train wrecks" over issues such as rare and endangered species and water pollution may possibly be avoided.

ACKNOWLEDGMENTS

We wish to thank the New Mexico Environment Department (Surface Water Quality Bureau), the U.S. Environmental Protection Agency and the New Mexico Natural Heritage Program of the Department of Biology at the University of New Mexico for their financial support of this project.

LITERATURE CITED

Bourgeron, P.S. and L.D. Engelking. eds. 1994. A preliminary vegetation classification of the United States. Unpublished report prepared by the Western Heritage Task Force for The Nature Conservancy, Boulder, CO.

Braun-Blanquet, J. 1965. Plant Sociology: the Study of Plant Communities. English translation of Pflanzensoziologie revised and edited by Fuller, G.D., and H.S. Conrad. Hafner Publishing Co., London, England.

Brown, D.E., C.H. Lowe, C.P. Pase. 1979. A digitized classification system for the biotic

communties of North America, with community (series) and association examples for the Southwest. Desert Plants 4 (1-4): 302-315.

Bullard, T.F. and S.G. Wells. 1992. Hydrology of the middle Rio Grande from Velarde to Elephant Butte Reservoir, New Mexico. Resource publ. no. 179, U.S. Department of the Interior Fish and Wildlife Service, Washington, DC.

Bureau of Reclamation. 1995. Hydrologic and hydraulic analysis for a riparian and wetland vegetation classification. Unpublished report prepared by U.S. Department of the Interior, Bureau of Reclamation Technical Assistance to States Program, Albuquerque Projects Office for the New Mexico Environment Dept., Santa Fe, NM and the New Mexico Natural Heritage Program, Albuquerque, NM.

Busch, D.E. and M.L. Scott. 1995. Western riparian ecosystems. In: Our Living Resources: A Report to the Nation on the Distribution, Abundance, and Health of U.S. Plants, Animals, and Ecosystems. E.T. LaRoe, G.S. Farris, C.E. Puckett, P.D. Doran, and M.J. Mac eds. U.S. Department of the Interior—National Biological Service, Washington, DC.

Carothers, S.W. 1977. Importance, preservation and management of riparian habitat: an overview. In: Importance, Preservation and Management of Riparian Habitat: A Symposium. R.R. Johnson and D.A. Jones tech coord. Gen. Tech. Rep. RM-43: U.S. Department of Agriculture Forest Service.

Cowardin, L.M., V. Carter, F.C. Golet, and E.T. LaRoe. 1979. Classification of Wetlands and Deepwater Habitats of the United States. FWS/OBS-79/31. USDI Fish and Wildlife Service, Washington, DC.

Crawford, C.S., Cully, A.C., Leutheuser, R., Sifuentes, M.S., White, L.H., Wilber, J.P. 1993. Middle Rio Grande ecosystem: bosque biological management plan. R. Robino, technical coordinator. U.S. Department of the Interior Fish and Wildlife Service, Albuquerque, NM.

Daubenmire, R.F. 1968. Plant Communities: A Textbook of Plant Synecology. Harper & Row, New York, NY.

Donahue, R.L., R.W. Miller and J.C. Shickluna. 1983. Soils: An Introduction to Soils and Plant Growth. Fifth ed. Prentice-Hall, Inc., Englewood Cliffs, NJ.

Driscoll, R.S., D.L. Merkel, D.L. Radloff, D.E. Snyder and J.S. Hagihara. 1984. An ecological land classification framework for the United States. USDA Forest Service Misc. publ. no. 1439. U.S. Government Printing Office, Washington, DC.

Durkin, P., M. Bradley, S.E. Carr, E. Muldavin and P. Mehlhop. 1995. Riparian/Wetland Vegetation Communities of the Rio Grande: A Classification and Site Evaluation. Unpublished final report submitted to the New Mexico Environment Department, Surface Water Quality Bureau, Santa Fe, NM.

Fenner, P., W.W. Brady, and D.R. Patton. 1985. Effects of regulated water flows on regeneration of Fremont cottonwood. Journal of Range Management, 38 (2): 135-138.

Grant, G.E., J.E. Duval, G.J. Koerper and J.L. Fogg. 1992. XSPRO: A Channel Cross Section Analyzer. U.S. Department of the Interior— Bureau of Land Management and U.S. Department of Agriculture Forest Service, Technical Note 387, BLM/SC/PT-92/001 + 7200, Denver, CO.

Hink, V.C. and R.D. Ohmart. 1984. Middle Rio Grande biological survey. Unpublished final report submitted in fulfillment of Army Corps of Engineers Contract No. DACW47-81-0015.

Howe, W.H. and F.L. Knopf. 1991. On the imminent decline of Rio Grande cottonwoods in central New Mexico. The Southwestern Naturalist 36 (2): 218-224.

Knopf, F.L., Johnson, R.R., Rich, T., Samson, F.B. and R.C. Szaro. 1988. Conservation of riparian ecosystems in the United States. Wilson Bulletin 100: 272-284.

Leonard, S.G., G.J. Staidl, K.A. Gebhardt, and D.E. Prichard. 1992. Viewpoint: range site/ecological site information requirements for classification of riverine riparian ecosystems. Journal of Range Management 45 (5): 431-435.

Mueller-Dombois, D. and H. Ellenberg. 1974. Aims and Methods of Vegetation Ecology. John Wiley and Sons, New York, NY.

National Wetlands Inventory. 1984. Wetlands of the United States: current status and recent trends. U.S. Department of the Interior Fish and Wildlife Service, Washington, DC.

Pase, C.P. and E.F. Layser. 1977. Classification of riparian habitat in the southwest. In: Importance, Preservation and Management of Riparian Habitat: A Symposium. R.R. Johnson and

D.A. Jones tech coord. Gen. Tech. Rep. RM-43: U.S. Department of Agriculture Forest Service.

Podani, J. 1990. SYNTAX IV: Computer Programs for Data Analysis in Ecology and Systematics on IBM-PC and MacIntosh Computers. United Nations Industrial Development Organization. International Centre for Earth, Environmental and Marine Sciences and Technologies. Exeter Publishing, Ltd., Setauket, NY.

Roelle, J.E. and W.W. Hagenbuck. 1995. Surface cover changes in the Rio Grande floodplain, 1935-89. In: Our Living Resources: A Report to the Nation on the Distribution, Abundance, and Health of U.S. Plants, Animals, and Ecosystems. E.T. LaRoe, G.S. Farris, C.E. Puckett, P.D. Doran, and M.J. Mac eds. U.S. Department of Interior—National Biological Service, Washington, DC.

Siegel, R.S. and J.H. Brock. 1990. Germination requirements of key southwestern woody riparian species. Desert Plants. University of Arizona, Boyce Thompson Southwestern Arboretum 10 (1): 3-8.

Soil Conservation Service. 1991. National Soils Handbook. USDA Soil Conservation Service. Washington, DC.

Soil Survey Staff. 1992. Keys to Soil Taxonomy. SMSS Tech. Monograph, Fifth ed. Pocahontas Ress, Inc., Blacksburg, VA.

Stromberg, J.C., B.D. Richter, D.T. Patten, and L.G. Wolden. 1993. Response of a Sonoran riparian forest to a 10-year return flood. Great Basin Naturalist 53 (2): 118-130.

Waltemeyer, S.D. 1986. Techniques for estimating flood-flow frequency for unregulated streams in New Mexico. Water-Resources Investigation Report 86-4104. U.S. Geological Survey, Albuquerque, NM.

Riparian habitat change along the Isleta-Belen reach of the Rio Grande

Joanne Mount[1,2], William Krausman[1], and Deborah M. Finch[2]

Abstract.—We provide a summary of vegetation changes over a 11-year period (1984-1995) in the middle reach of the Rio Grande. Hink and Ohmart (1984) surveyed and mapped riparian vegetation along the middle Rio Grande as part of an extensive biological inventory conducted for the Army Corps of Engineers. We field-assessed and remapped the Isleta-Belen reach in 1995 to determine whether vegetation classes had changed substantially since the Hink and Ohmart survey. Over the past 11 years, the Rio Grande bosque vegetation has aged, and our assessment of structural types documents this aging process. In addition, the exotic woody species, salt cedar (*Tamarix chinensis*) and Russian olive (*Eleagnus angustifolia*), have increased in cover, appearing as understories in Rio Grande cottonwood (*Populus fremontii* var. *wislizenii*) galleries and as independent vegetational communities. In some cases, these introduced species have replaced other vegetation such as coyote willow (*Salix exigua*). We also detected evidence of 31 fire events that altered vegetation.

INTRODUCTION

One of the largest cottonwood gallery forests in the Southwest is found along the middle Rio Grande. The value of this riparian habitat has become widely recognized over the past 20 years. It serves as habitat for a wide range of wildlife including endangered species such as the southwestern willow flycatcher (*Empidonax trailii extimus*), it provides ample recreation opportunities, and also contributes to flood control by stabilizing soils and river banks.

Hink and Omart (1984) conducted a biological survey of the middle reach of the Rio Grande to identify and describe the major riparian habitat types within the bosque and the wildlife species that inhabit different types. The major vegetation communities that they found were Cottonwood/Russian Olive, Cottonwood/Coyote Willow, Cottonwood/Juniper, Russian Olive, Cattail Marsh, Salt Cedar, and Sandbar/River Channel. The Middle Rio Grande Biological Survey led to the development of six community-structure types which were used to create detailed riparian vegetation maps.

There have been significant natural and human induced changes along the middle Rio Grande since 1984. Fire, exotic plant invasions, changing channel morphometry, reduced flooding, human disturbances such as borrow pits and urban encroachment, and succession and aging of woody plants have all contributed to altering the pattern and structure of the bosque vegetation communities. The vegetation maps generated in 1984 are now of limited value to those interested in the ecology and environmental quality of the middle Rio Grande. In 1995, the U.S. Army Corps of Engineers in Albuquerque contracted the USDA Forest Service Rocky Mountain Forest and Range Experiment Station, Albuquerque Laboratory, to re-map the riparian vegetation along the middle

[1] *USDA Forest Service, Southwest Region, Federal Building, 517 Gold Ave., Albuquerque, NM 87102.*

[2] *USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, 2205 Columbia SE, Albuquerque, NM 87106.*

Rio Grande. Mapping was performed by the Geometronics Remote Sensing Unit of the USDA Forest Service's Southwestern Region through an interagency agreement. The 1995 middle Rio Grande vegetation maps were displayed on our poster and will be available in our final report to the Albuquerque Corps of Engineers due out by December 1995. They are not reproducible in the format required for the symposium proceedings.

The maps for the poster displayed areas of the bosque where there have been minor and major vegetation changes since 1984 in addition to providing annotations that define the current vegetation type for each polygon. An annotated 1984 vegetation map prepared by Hink and Ohmart (1984) (on file, Albuquerque Corps of Engineers) was used to directly compare and qualitatively assess vegetation changes over this 11-year period. Our final report will visually display the two sets of maps from 1984 and 1995 and provide a statistical analysis of change. For the purposes of this symposium paper, we will briefly describe the methodology we used and the qualitative changes detected by our mapping project.

METHODS

The scope of the mapping project began at the Interstate 25 overpass south of Albuquerque and continued for 25 miles to the Bosque Bridge south of Belen. Vegetation between the flood control levees on both sides of the river was mapped using 1:3,000 scale black and white aerial photography. Vegetation polygons were defined through stereoscopic interpretation of the imagery. Particular emphasis was paid to polygons that seemed to differ structurally from those on the 1984 maps: these polygons were marked and checked in the field.

Vegetation type and structure were visually classified based on Hink and Ohmart's (1984) definition. Imagery for current vegetation was acquired in January when the vegetation was not in leaf. Vegetation classes were often difficult to interpret in many polygons as a result. Polygons that could not be confidently classified using image interpretation were also marked for on-the-ground field assessment. Because of the difficulty in interpreting vegetation structure or type from the photography, especially understory species, and because vegetation structure and type seemed to have changed considerably from what is shown on the 1984 maps, nearly every mapped polygon was visited and assessed on the ground. Consequently, it was unnecessary to perform a traditional remote sensing accuracy assessment, and none was undertaken.

Vegetation structure and type were assessed on the ground using an ocular methodology. Field personnel were "calibrated" by placing two bisecting, 50 meter line-intercept transects in each structural class. The intercept of all individual trees in excess of four meters high was cumulatively measured and recorded by species; heights were measured using a clinometer. The cumulative intercept distance for understory species (those less than four meters high) was also recorded by species. Percentage cover by species and structural class was calculated from the data. This methodology allowed field personnel to develop a familiarity with the vegetation communities making ocular assessment on successive polygons possible. Field personnel periodically collected additional line-intercept transect data to assure that their ocular estimates were correct. In excess of 50 sites were measured using line intercept techniques, 43 of which were located using a Global Positioning System.

Updated map polygon boundaries and classification data were subsequently entered into Arc/Info and the Intergraph Microstation GIS and mapping environments for quantitative analysis and map production. The quantitative analysis of vegetation change in the Middle Rio Grande will be completed by November 1, 1995.

MAPPING RESULTS

A qualitative analysis of the vegetation change along the newly mapped portion of the middle reach of the Rio Grande indicates significant differences in vegetation class and species presence between 1984 and 1995. In particular:

- An increase in cover by Russian olive.
- Continued invasion of salt cedar, and attendant replacement of coyote willow by salt cedar.
- Evidence of fire (both natural and that of human origin) indicates it to be significant factor in vegetation change in the bosque.
- The bosque is maturing as indicated by an increase in the number of polygons in the

larger structural classes, and also by a decrease in the number of coyote willow polygons.

In numerous polygons that contained Russian olive in 1984, vegetation structure has changed as individual plants have matured. Numerous polygons have changed from structural class 5 to 3 (see fig. 1 for general depiction of vegetation structural types) as a result of increased height and density of Russian olive in the middle story of the canopy. Further, a number of polygons that did not support Russian olive in 1984 now have the species in the understory.

Salt cedar has been a vigorous invader of southwestern riparian habitats, and continues to advance steadily in the Rio Grande bosque. Numerous vegetation polygons that did not have salt cedar in 1984 now contain the species. Further, coyote willow has been replaced by salt cedar in a number of polygons. The addition of salt cedar as a polygon component is perhaps the most widespread and obvious change that has occurred since the 1984 maps were produced.

Our field assessment identified 31 fires within the study area since 1984, making fire a significant contributor to vegetation change. On burned polygons, the first woody species that appeared to return was coyote willow, followed by salt cedar, then Russian olive, and finally, cottonwood.

A number of changes in vegetation structure and types within the mapped polygons indicates that the Rio Grande bosque is maturing. Numerous polygons have changed from structure class 5 to 3 as previously mentioned, and a few stage 3 polygons have reached structure stage 1. Furthermore, most of the stage 1 polygons have additional species (e.g., salt cedar, Russian olive) in their understory, and the number of sites containing coyote willow is decreasing - pointing to successional, maturing vegetation. Interestingly, field assessment showed that while the bosque vegetation is aging, cottonwood recruitment appeared low. The majority of cottonwood trees in the bosque date back to 1941, when the Rio Grande experienced a major flood (Funk 1993). Regulation of flooding events and reduction of water quantity in the Rio Grande may contribute to low cottonwood regeneration.

CONCLUSION

The 1995 middle Rio Grande vegetation maps indicate that vegetation classes and species composition have changed extensively since 1984. Overall, the bosque is aging as detected by vegetation growth and maturation using structural stage assessment. Non-endemic woody species are becoming more prominant, often appearing as understory species in cottonwood woodland, and also as shrub communities without cottonwoods (see fig. 1 on next page). Because wildlife species are associated (sometimes strongly) with vegetation type and structure, it is clear that as bosque vegetation changes and matures, species composition and population sizes of various species of bosque fauna will change. Such shifts may have already taken place, but long-term monitoring data are needed to detect changes in animal populations. We recommend long-term monitoring programs be established to detect further changes in bosque flora and fauna. Monitoring data are necessary to ensure a scientific basis for establishing goals and priorities for bosque conservation and restoration.

The middle Rio Grande vegetation maps were created to provide baseline vegetation data to help address this and many other topics critical to the successful management of the Rio Grande.

ACKNOWLEDGMENTS

We thank Ed Benally for technical help and the Albuquerque Army Corps of Engineers for funding this project. We are grateful to William DeRagon, Mark Sifuentes, and Jeff Whitney for their guidance.

LITERATURE CITED

Crawford, C. S., A. C. Cully, R. Leutheuser, M. S. Sifuentes, L. H. White, J. P. Wilber. 1993. Middle Rio Grande ecosystem: Bosque biological management plan. U.S. Fish and Wildlife Service, Albuquerque, NM. 291 p.

Funk, R. 1993. Rio Grande Valley State Park. Pp. 159-161 *In* B. Tellman, J.J. Cortner, M. G. Wallace, L. F. DeBano, R.H. Hamre, technical coordinators. Riparian management: common threads and shared interests. USDA Forest Service. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. General Technical Report RM-226.

Hink, V. C., and R. D. Ohmart. 1984. Middle Rio Grande Biological Survey. Final Report. Army Corps of Engineers Contract No. DACW47-81-C-0015. Tempe, AZ: Center for Environmental Studies, Arizona State Univ. 160 p.

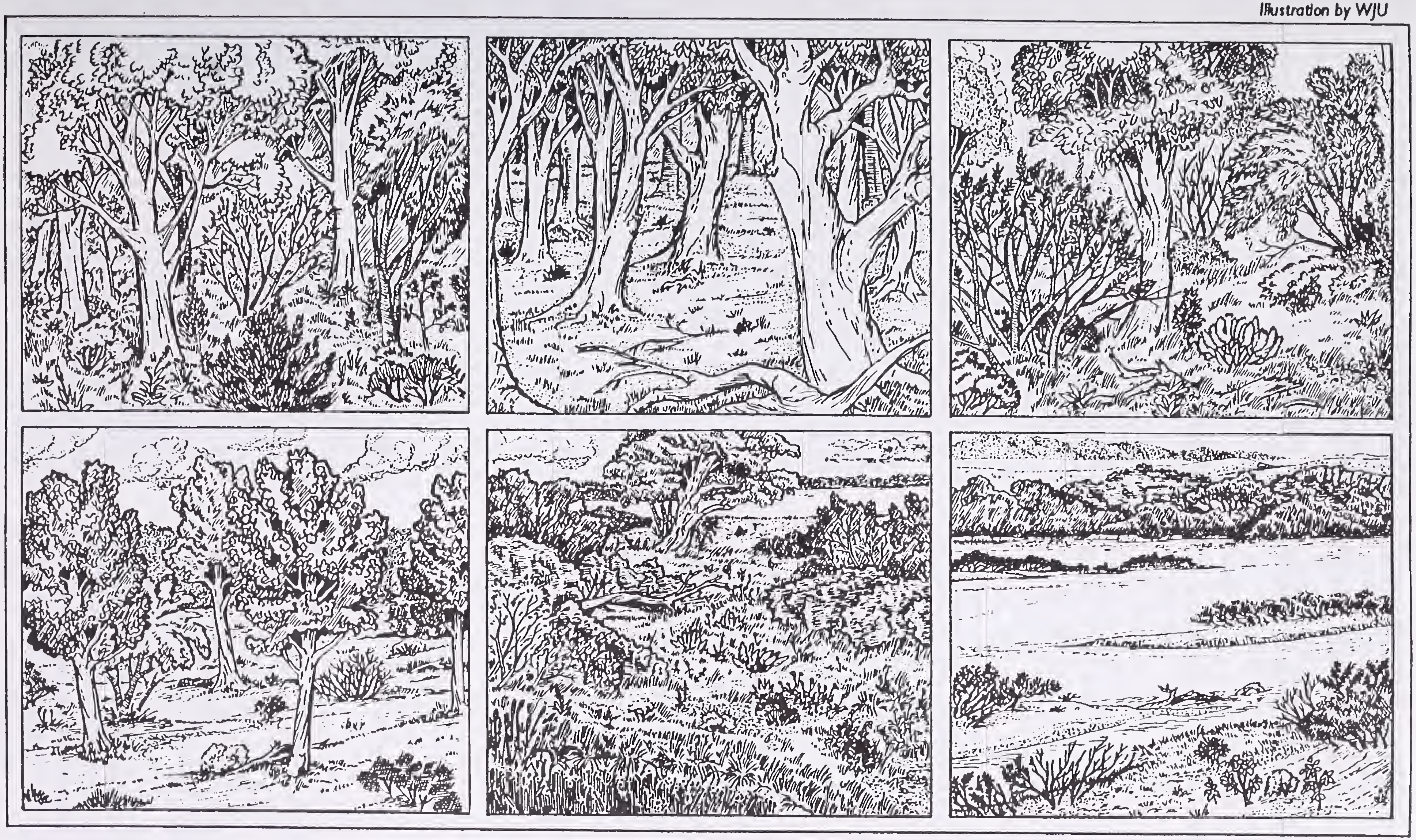


Figure 1. Vegetation structural types I-VI along the middle Rio Grande (from Crawford et al 1993, Hink and Ohmart 1984).

Avian community composition and habitat importance in the Rio Grande corridor of New Mexico

David A. Leal[1], Raymond A. Meyer[2], and Bruce C. Thompson[2]

Abstract.—We investigated avian species richness and abundance within vegetation communities of the Rio Grande Corridor of New Mexico during spring, summer, and fall 1992 and 1993. A subset of 64 transects, for which all bird and vegetation variables were available, representing 16 composite vegetation community types were subjected to canonical correlation analysis to investigate relative habitat importance. Generally, the higher ranking community types had cottonwood and other native woody species as dominants and the lower ranking communities were those types that are highly manipulated and/or monotypic, such as mowed river edge, pecan orchards, and relatively pure stands of saltcedar. Bird occurrence and distribution in the Rio Grande Corridor is not so neatly related to composition of native vegetation as is sometimes characterized. Exotic plant species such as saltcedar and Russian olive, are utilized to varying degrees by the existing avian community. Ranking of avian use by habitat types may help direct restoration efforts towards situations where more significant gains in avian use can be made.

INTRODUCTION

Concerns about declines in many neotropical migrant (NTM) bird species (Robbins et al. 1989, Finch 1991, and Finch and Stagel 1992) have heightened the interest in conservation, monitoring, and research concerning these species and their habitats. It is important to the management of the Rio Grande Corridor to understand and monitor faunal use patterns in the changing mosaic of existing habitats. In New Mexico, these habitats include (1) natural riparian habitats dominated by native Fremont cottonwood (*Populus fremontii* var. *wislizenii*) and/or willow (*Salix* spp.) with differing degrees of exotic saltcedar (*Tamarix chinensis*) and/or Russian olive (*Elaeagnus angustifolia*) encroachment, (2) monotypic stands of exotic saltcedar or Russian olive, (3) marshes primarily dominated by cattail (*Typha* spp.) and hardstem bulrush (*Scirpus acuta*), (4) mowed river edge areas dominated by grasses such as alkali sacaton (*Sporobolus airoides*), (5) active agricultural areas such as pecan (*Carya illinoensis*) orchards and row crops, and (6) manipulated riparian areas associated with agricultural irrigation channels generally dominated by wolfberry (*Lycium* spp.) and fourwing saltbush (*Atriplex canescens*).

The Rio Grande Valley of New Mexico has undergone a large scale conversion from bosque (riparian woodlands) dominated by Fremont cottonwood and/or native willows to either exotic saltcedar and/or Russian olive dominated stands (Van Cleave 1935, Freehling 1982, Howe and Knopf 1991, Crawford et al. 1993, Ellis 1994) or

[1] *New Mexico Ecological Services State Office, 2105 Osuna NE, Albuquerque, NM 87113.*

[2] *National Biological Service,New Mexico Cooperative Fish and Wildlife Research Unit, New Mexico State University, Las Cruces, NM 88003.*

agricultural "habitats" (Crawford et al. 1993). Additionally, the historic Rio Grande watercourse has been extensively dammed and channelized for flood control and to manage agricultural and urban water needs. This alteration has effectively eliminated the seasonal scouring floods needed to promote regeneration of native vegetation (Minckley and Brown 1982, Howe and Knopf 1991). Crawford et al. (1993) thoroughly reviewed and summarized the historic channel and habitat changes that have led to the existing conditions in the Middle Rio Grande of New Mexico. However, in the Rio Grande Valley south of Caballo Reservoir, native riparian vegetation communities have been almost entirely replaced by an intensively managed agricultural environment. Bordering the channelized river is a levee system within which vegetation is strictly controlled. Few remnant patches of riparian vegetation remain.

The importance of natural riparian habitat to the associated avian communities in the southwestern United States has become recognized only in the last two decades (Smith 1975, Johnson and McCormick 1978, DeGraff 1980; Schmitt 1976; Johnson and Jones 1977; Hundertmark 1978; Warner and Hendrix 1984). Breeding birds of southwestern riparian habitats have been categorized according to their dependence upon riparian vegetation (Hubbard 1971, Hubbard and Hayward 1973, Schmitt 1976, Hundertmark 1978). Although these areas comprise a small portion of the landscape, they are recognized as concentrations of high biotic diversity with unique assemblages of flora and fauna. Studies have found that more than 60% of vertebrates found in these systems of the southwest are obligate to them (Ohmart and Anderson 1982). Hubbard (1977) reported 16-17% of the breeding avifauna of North America were found in the Gila and San Juan river valleys of New Mexico with roughly 25% of these species restricted to the riparian habitat. Riparian habitat also provides important resources for birds during spring and fall migration. Stevens et al. (1977) found ten times greater bird density in riparian habitats as opposed to adjacent upland habitats.

A great deal of concern has been raised over the reduction, fragmentation, and degradation of native riparian vegetative communities and the subsequent effects on faunal diversity and abundance. In some situations, bird density is increased by the presence of agricultural land adjacent to riparian habitat providing a major food source to certain species (Carothers et al. 1974, Conine et al. 1978, Anderson et al. 1984). Extreme alteration of a riparian system, however, can have negative effects on the native avian community. Species of birds are expected to decline and, perhaps, eventually abandon riparian systems where replacement of native vegetation occurs (Raitt and Delesantro 1980, Hunter et. al. 1987). Conine et al. (1978) found that 21 "riparian species" did not use agricultural habitats in the lower Colorado River Valley. Klebenow and Oakleaf (1984) observed a decrease in species number and species densities in the avian community historically inhabiting a riparian system in Nevada as a result of severe reduction and alteration of native vegetation.

Large scale research projects in the Southwest have investigated avian use of riparian habitat on the lower Colorado River in California and Arizona (Anderson et al. 1977a), lower Rio Grande in Texas (Engel-Wilson and Ohmart 1978), middle Rio Grande in New Mexico (Hink and Ohmart 1984), and Pecos River in New Mexico and Texas (Hunter et al. 1988). Research by Engel-Wilson and Ohmart (1978) on the Rio Grande near Presidio, Texas, differed in most of the vegetative types studied and the fact that cottonwood/willow habitat types were uncommon in their study area. The Middle Rio Grande Biological Survey (MRGBS) conducted by Hink and Ohmart (1984) for the U.S. Army Corps of Engineers was an intensive survey of floral and faunal conditions in the middle Rio Grande Valley of New Mexico from Española, Rio Arriba County, to San Acacia, Socorro County, New Mexico, with a core study area from Bernalillo, Sandoval County, to the town of Bosque, Valencia County. Results from the MRGBS have been the primary management reference for federal agencies when addressing biological effects in the bosque of the Rio Grande in New Mexico.

Hink and Ohmart (1984) found 277 species of birds, 239 of which were considered to be in their normal range. This represented approximately 60% of the birds known to occur in New Mexico. Approximately 85 to 95 of these species were suspected to breed in the middle Rio Grande of New Mexico. Species richness values for the MRGBS ranged from a low of 7 to a high of 55 species for selected vegetation Community/Structure (C/S)

types per season. Species richness for cottonwood C/S types ranged from 30 to 50 species. Densities estimated by Hink and Ohmart (1984) ranged from 300 to 500 birds/100 acres (40 ha) for cottonwood C/S types and reached highs of up to 1000 birds/100 acres (40 ha) during migration for certain C/S types. Other studies of avian use of riparian habitats (including restored sites) in the Rio Grande Valley of New Mexico have been completed (King 1976; Jojola 1977; Cole 1978; Hundertmark 1978; Raitt and Delasantro 1980; Freehling 1982; Hoffman 1990; Ellis 1994; Farley et al. 1994a,b) however, most were limited in geographic area and none represented more than nine vegetation types.

As native cottonwood dominated habitat patches are lost to attrition or through fires and the area occupied by riparian habitats is reduced, large scale habitat restoration efforts will be crucial to maintain any native habitat diversity. Farley et al. (1994a,b) assessed avian use of different age sites revegetated with native plant species relative to mature woodlands in the Middle Rio Grande Valley. Results showed that revegetated sites were important to NTM species. Avian communities at older sites were most similar to those present in mature woodland.

We investigated the hypothesis that Rio Grande vegetation types represent a gradient of relative importance to NTM birds that can be estimated from correlations of species presence and abundance with vegetation structural features. Objectives involved sampling bird presence and relative abundance among representative vegetation tracts, and performing multivariate analysis of bird detection among vegetation community types. To be useful in conservation decision-making, data were collected and analyzed for all bird species in the corridor; NTM bird occurrence was evaluated in context with the entire assemblage of birds species associated with the corridor when NTM species were present.

STUDY AREA AND METHODS

The study area followed the flood plain of the Rio Grande in New Mexico with the northern boundary 2 to 3 km north of Velarde, Rio Arriba County, at the south end of the Cañon del Rio Grande. The southern boundary was located near Mesquite, Doña Ana County, New Mexico. This portion of the Rio Grande was approximately 480 km long with the flood plain varying in width. The study area was divided into five strata approximately representing the surrounding biotic communities described by Brown and Lowe (1980). Biotic communities which the study area passed through include; Great Basin Grassland, Great Basin Conifer Woodland, Plains and Great Basin Grassland, Semidesert Grassland, and Chihuahuan Desertscrub. Stratification of the study area along these boundaries was considered necessary because biotic communities contain different vegetation influences and avian assemblages, thus potentially contributing different species to riparian areas transecting those biotic communities.

Habitat C/S types were determined following Hink and Ohmart (1984) who derived their classification based on Brown et al. (1979) and information from W.A. Dick-Peddie (unpublished report to New Mexico Natural Heritage Program, 1981). A community type is a distinct assemblage of plant species with species ranked as to dominance and codominance within canopy layers. Species composing 50% or more of a canopy layer were considered dominant. Species composing 25 to 50% of a canopy layer were considered codominant. Six basic structure types were determined by ocularly ranking the dominant and codominant overstory, midstory, and understory vegetation species. Structure types I and II both represent mature stands with well developed upper canopies generally of cottonwood. Types I and II were distinguished by the degree of development of the middle and lower vegetation layers. Type I had well developed structure from the ground up while type II was lacking significant middle and lower canopies. Types III and IV were intermediate in size with the two differing in development of the mid and lower canopy layers. Type III had a well developed lower canopy layer while type IV did not. Structure types V and VI were small in size class with little to no middle canopy layer. Type V was typically characterized by a dense lower canopy layer while type VI had all the vegetation in the lower canopy layer but it was sparse. This process defined an individual C/S type description for each transect.

Avian surveys were conducted during breeding (summer) and migration (spring and fall) periods from 1 June 1992 through 30 September 1993; the

winter period from mid-October to mid-April was not sampled. Avian surveys essentially followed transect techniques developed by Emlen (1971) with modifications as described by Anderson et al. (1977b) and used by Hink and Ohmart (1984) to facilitate comparability. Data on individual birds detected (audibly and/or visually) included side of the transect where detected and lateral distance from transect line.

Primary bird sampling was conducted on 72, 500 m long variable distance transects representing 49 different vegetation C/S types for which vegetation structure was measured in summer 1993. This sampling provided data for analyzing bird richness, relative abundance, and biomass relative to 17 vegetation structure variables. Incidental species observations within the study area were recorded for use in historical comparisons with avian assemblages derived from ornithological literature review.

Analyses included data from 64 transects for which there were data for all variables. These 64 transects represented 49 different C/S types comprising 16 composite types based on community composition and dominance similarities. These multivariate procedures did not allow use of records that lacked data for 1 or more variables.

Variables concerning bird detection and vegetation structure were subjected to canonical correlation analysis (CCA) to evaluate multivariate interrelationships among the variables and for ordination of transects representing different C/S types. CCA is a process that operates on 2 related sets of variables and develops linear combinations of the 2 respective variable sets such that correlation is maximized between the resultant linear combinations. There are as many canonical variates as the number of variables in the smaller set of original variables. The CCA process as applied to these data sets was described in greater detail by Cooley and Lohnes (1971), Smith (1981), and Jongman et al. (1987). CCA was used initially to compute 3 canonical variates derived from the 3 bird detection variables relative to 17 vegetation structure variables. Calculations were performed on standardized variable values to eliminate influences of different magnitudes of scale in the original variables. Redundancy analysis (Cooley and Lohnes 1971) was then performed to examine the degree of relationship of original variables in each set to their respective canonical variate and to the canonical variates calculated for the opposite set. CCA was performed on all avian species and NTM bird species seperately.

Significant canonical variates and canonical scores for vegetation C/S types of individual transects were examined for pattern. Comparable variates that were interpretable relative to composite vegetation community types were used further to select rankings of composite communities. The signed cross-product (cross-products of two negative scores were treated as negatives) was calculated from the bird and vegetation scores for each transect. These cross-products were averaged within composite community types and the signed magnitude of the mean value was used to order the communities relative to anticipated importance to groups of birds.

RESULTS

Field work during both years detected 259 bird species of which 162 species were observed on transects in study tracts. For all bird species observed during our sampling, 147 were NTM species as defined by the Partners in Flight program (Gautheraux 1992). Species richness values varied from 12 to 49 species among the primary transects. There were 30 of the 72 transects (41.7%) that had ≥ 35 bird species in composite over all surveys in all seasons. These 30 transects were broadly distributed among vegetation community types, but Russian olive and saltcedar were at least codominant species in 53% of these richest sites and were the dominant species at 20% of the richest sites. Fewer species were detected at monotypic stands of salt cedar. Young stands of cottonwood-willow had low bird richness values but were important recruitment for future riparian woodlands and were important to bird species that prefer early successional stages. Relative avian abundance values varied from 15 to 260 individuals during the breeding season and from 30 to 350 individuals for all seasons combined. The most frequently detected species were black-chinned hummingbird (*Archilochus alexandri*), blue grosbeak (*Guiraca caerulea*), and mourning dove (*Zenaida macroura*), but detections were too few to reliably estimate species densities among transects.

We performed canonical correlation analysis of three bird variables and 17 vegetation structure

variables for a subset of 64 primary transects (those having complete bird and vegetation data) representing 49 C/S types and 16 composite vegetation community types. Analyses were applied separately to (1) all bird species and (2) NTM species, for the breeding season and all seasons combined. For all species combined, there were two significant canonical variates each for all seasons and summer only. In each case, the first variate accounted for 65-70% of the variance and related bird biomass inversely to number and size of trees and directly to ground vegetation structure. The second variate for all species accounted for 48-53% of variation and related bird richness and abundance directly to number, size, and species count of small and large trees. For NTM species, there was one significant canonical variate (56-57% of variation accounted) each for all seasons combined and for summer only. Both variates related bird richness and abundance to ground herbaceous structure, tree number, and tree size; however, the summer only variate differed from all seasons in that bird richness and abundance were inversely correlated and presence of large trees had greater influence on bird importance scores in summer (Table 1).

DISCUSSION

There was no single vegetation variable or multivariate construct that definitively placed each transect or C/S category above or below any other site. Ordering of composite vegetation community type importance based on signed cross-products of canonical scores for the 64 transects produced similar rankings for all species and NTM species across seasons and all species in summer, but ranking differed for NTM in summer only (Table 1). Generally, higher ranking composite community types had cottonwood and other native woody species as dominants. Lower ranking communities were those types that are highly manipulated (mowed river edge, pecan orchards) or had extensive composition of salt cedar or other exotic woody species. Some more simply structured vegetation types (i.e., salt cedar-willow-cottonwood) had low bird value in composite but represented sites important to sensitive species and are important as early stages of what should progress into well-developed riparian woodland.

Our analyses provide "point-in-time" relative values of communities evaluated, but should not be interpreted as categorical values applicable to specific sites over a long term. This research also provides a landscape view of ranked vegetation community importance to birds in the Rio Grande Corridor that should be assessed by resource managers for compatibility with priorities for maintaining other elements of nature.

Table 1. Relative ranked importance (1=highest) for 16 composite community/structure types (based on mean signed cross products of comparable canonical variate scores among transects) for all bird species (ALL) combined and for Neotropical migrant (NTM) bird species during the summer sampling season and for all seasons combined within the Rio Grande Corridor, New Mexico, 1992-1993.

Relative rank[a] community (species)[b,c]	All seasons		Summer	
	ALL	NTM	ALL	NTM
SC	14	16	13	8
C/RO	10	11	8	11
C/(RO-SC)	9	7	10	10
C/(Exotic-WI)	11	9	12	5
(ME-SC)	8	8	11	6
C/(RO-J)	12	13	7	2
C/(NO-etc.)	1	4	1	3
C/(ME-etc.)	2	5	3	9
(SC-WI-C)	15	14	15	13
RO	5	3	4	14
C	7	10	5	4
C/SC	3	6	2	1
C/(WI-etc.)	4	2	9	12
MARSH	6	1	6	16
MOWED RIVER EDGE	16	15	16	15
PECAN	13	12	14	7

[a] *Rank is based on score cross-products (average among transects within composite categories) for the respective species richness and abundance dominated canonical variates for all species (CV2) and NTM species (CV1). Negative signs were given to cross-products for which one or both canonical scores were negative.*

[b] *C=cottonwood, J=juniper, ME=mesquite, NO=New Mexico olive, RO=Russian olive, SC=saltcedar, SE=Siberian elm, WI=willow*

[c] *Composite C/S types: C/(RO-SC) includes C/RO-SC and C/SC-RO; C/(Exotic-WI) includes C/WI-RO, C/SC-WI, C/WI-SC, C/WI-SE, and C/WI-RO, SC; (ME-SC) includes ME-SC and SC-ME; C/(RO-J) includes C/J and C/RO-J; C/(NO-etc.) includes C/RO-NO, C/NO-WI, and C/NO-SE; C/(ME-etc.) includes C/ME, C/ME-RO, C/ME-SC; (SC-WI-C) includes SC-WI-C, SC-WI, WI-C, and C-WI; C/(WI-etc.) includes C/WI, C/WI-Marsh, and C/WI-Restored*

LITERATURE CITED

Anderson, B.W., A.E. Higgins, and R.D. Ohmart. 1977a. Avian use of saltcedar communities in the lower Colorado River valley. pp. 128-136. *in* R.R. Johnson and D.A. Jones (tech coords.), Importance, Preservation, and Management of Riparian Habitats: a Symposium. U.S. Forest Serv. Gen. Tech. Rep. RM-43.

Anderson, B.W., R.W. Engel-Wilson, D. Wells, and R.D. Ohmart. 1977b. Ecological study of southwestern riparian habitats: techniques and data applicability. pp. 146-155 *in* R.R. Johnson and D.A. Jones (tech coords.), Importance, Preservation, and Management of Riparian Habitats: a Symposium. U.S. For. Serv. Gen. Tech. Rep. RM-43.

Anderson, B.W., R.D. Ohmart, and H.A. Allen, Jr. 1984. Riparian birds in the riparian/agricultural interface. pp. 190-195 *in* R.E. Warner and K.M. Hendrix, eds. California riparian systems: ecology, conservation, and productive management. Univ. of California Press, Berkeley.

Brown, D.E., and C.H. Lowe. 1980. Biotic communities of the Southwest. U.S. Dep. of Agric. For. Serv. Gen. Tech. Rep. RM-78.

Brown, D.E., C.H. Lowe, and C.P. Pase. 1979. A digitized classification system for the biotic communities of North America, with community (series) and association examples for the Southwest. J. Ariz-Nev. Acad. Sci. 14(Suppl. 1):1-16.

Carothers, S.W., R.R. Johnson, and S.W. Aitchison. 1974. Population structure and social organization of Southwestern riparian birds. Amer. Zool. 14:97-108.

Conine, K.H., B.W. Anderson, R.D. Ohmart and J.F. Drake. 1978. Responses of riparian species to agricultural habitat conversions. pp. 248-262 *in* Strategies for protection and management of floodplain wetlands and other riparian ecosystems. Gen. Tech. Rep. WO-12. U.S. For. Ser., Wash. D.C.

Cooley, W.W. and P.R. Lohnes. 1971. Multivariate data analysis. John Wiley and Sons, Inc. New York, NY 211 pp.

Crawford, C.S., A.C. Cully, R., Leutheuser, M.S. Sifuentes, L.H. White, and J.P. Wilber. 1993. Middle Rio Grande ecosystem: Bosque biological management plan. 291 pp.

DeGraff, R.M., tech. coord. 1980. Management of Western Forests and Grasslands for Nongame Birds. Gen. Tech. Rep. INT-86. Intermountain For. and Range Exp. Sta., Ogden, Utah.

Dick-Peddie, W.A. 1993. New Mexico Vegetation, Past, Present, and Future. University of New Mexico Press. Albuquerque, 244 pp.

Ellis, L.M. 1994. Bird use of saltcedar and cottonwood vegetation in the Middle Rio Grande Valley of New Mexico, U.S.A. J. Arid Environments (in press).

Emlen, J.T. 1971. Population densities of birds derived from transect counts. Auk 88:323-342.

Engel-Wilson, R.W., and R.D. Ohmart. 1978. Floral and attendant faunal changes on the lower Rio Grande between Fort Quitman and Presidio, Texas. U.S. Dep. Agric. For. Serv. Gen. Tech. Rep. WO-12:139-147.

Farley, G.H., L.M. Ellis, J.N. Stuart, and N.J. Scott, Jr. 1994a. Avian species richness in different-aged stands of riparian forest along the Middle Rio Grande, New Mexico. Conservation Biology 8:(in press).

Farley, G.H., L.M. Ellis, J.N. Stuart, and N.J. Scott, Jr. 1994b. Birds of restored and mature riparian woodlands in the Middle Rio Grande Valley. New Mexico Ornithol. Soc. Bull. 22:25-33.

Finch, D.M. 1991. Population ecology, habitat requirements, and conservation of Neotropical migratory birds. U.S. Dep. Agric.-Forest Serv., Rocky Mtn. For. and Range Exp. Sta., Gen. Tech. Rep. RM-205. 26 pp.

Finch, D.M. and P.W. Stangel, eds. 1992. Status and management of Neotropical Migratory Birds. Gen. Tech. Rep. RM-229. Rocky Mountain For. and Range Exp. Sta. Fort Collins, CO.

Freehling, M.D. 1982. Riparian woodlands of the Middle Rio Grande Valley, New Mexico: A study of bird populations and vegetation with special reference to Russian Olive (*Elaeagnus angustifolia*). U.S. Fish and Wildl. Serv., Region 2, Albuquerque.

Gautheraux, S.A. 1992. Preliminary list of migrants for Partners in Flight Neotropical Bird Program. Partners in Flight 2:30.

Hink, V.C., and R.D. Ohmart. 1984. Middle Rio Grande biological survey - final report. Center for Environmental Studies, Arizona State Univ., Tempe, Arizona. (Army Corps of Engineers Contract #DACW 47-81-C-0015).

Hoffman, S, W. 1990. Bosque biological monitoring program: Bird population surveys in Rio Grande Valley State Park (1987-1990). City of Albuquerque, Land Resource & Regulation Department, Open Space Division, Contract #8901186.

Howe, W.H., and F.L. Knopf. 1991. On the imminent decline of Rio Grande cottonwoods in central New Mexico. Southwestern Naturalist 36:218-224.

Hubbard, J.P. 1971. The summer birds of the Gila Valley, New Mexico. Nemouria 2:1-35.

Hubbard, J.P., and B.J. Hayward. 1973. A biological survey of the San Francisco Valley with emphasis on habitats and vertebrates. Contracted study for U.S. Fish and Wildl. Serv., New Mexico.

Hubbard, J.P. 1977. Importance of riparian ecosystems: Biotic considerations. pp.14-18. *in* R.R. Johnson and D.A. Jones (tech coords.), Importance, Preservation, and Management of Riparian Habitats: a Symposium. Gen. Tech. Rep. RM-43. Rocky Mountain For. and Range Sta., Fort Collins, CO.

Hundertmark, C.A. 1978. Breeding birds of Elephant Butte Marsh. New Mexico Ornithol. Soc. Publ. No. 5.

Hunter, W.C., R.D. Ohmart, and B.W. Anderson. 1987. Status of breeding riparian-obligate birds in southwestern riverine systems. Western Birds 18:10-18.

Hunter, W.C., R.D. Ohmart, and B.W. Anderson. 1988. Use of exotic saltcedar (*Tamarix chinensis*) by birds in arid riparian systems. Condor 90:113-123.

Johnson, R.R. and D.A. Jones, tech. coords. 1977. Importance, Preservation and Management of Riparian Habitat: a Symposium. Gen. Tech. Rep. RM-43, Rocky Mountain For. and Range Exp. Sta., Fort Collins, CO.

Johnson, R. and J.F. McCormick, tech.coords. 1978. Strategies for Protection and Management of Floodplain Wetlands and Other Riparian Ecosystems. U.S. Forest Serv. Gen. Tech. Rep. WO-12.

Jojola, J.R. Sr. 1977. Bird populations and habitat in a riparian woodland, Isleta Indian Reservation, central New Mexico. Unpubl. M.S. Thesis. New Mexico State Univ., Las Cruces.

Jongman, R.H.G., C.J.F. ter Braak, and O.F.R. van Tongeren. Editors. 1987. Data analysis in community and landscape ecology. Centre for Agr. Publ. and Documentation (PUDOC), Wageningen, Netherlands. 299 pp.

King, H.T. 1976. Bird abundance and habitat in a southern New Mexico bosque. Unpubl. M.S. Thesis. New Mexico State Univ., Las Cruces.

Klebenow, D.A., and R.J. Oakleaf. 1984. Historical avifaunal changes in the riparian zone of the Truckee River, Nevada. pp. 203-209 *in* R.E. Warner and K.M. Hendrix, eds. California riparian systems: ecology, conservation, and productive management. Univ. of California Press, Berkeley.

Minckley, W.L., and D.E. Brown. 1982. Wetlands. In D.E. Brown Ed. Biotic Communities of the American Southwest-United States and Mexico. Desert Plants 4:1-342.

Ohmart, R.D., and B.W. Anderson. 1982. North American desert riparian ecosystems. pp. 433-479 *in* G.L. Bender, ed. Reference handbook on the deserts of North America.

Raitt, R.J., and M.C. Delesantro. 1980. Avifauna Census Elephant Butte and Caballo Reservoirs, New Mexico. U.S. Water and Power Resources Service, Rio Grande Project, Contract No. 9-07-54-V0507

Robbins, C.S., J.R. Sauer, R.S. Greenberg, and S. Droege. 1989. Population declines in North American birds that migrate to the neotropics. Proc. Natl. Acad. Sci., USA Vol. 86:7658-7662.

Schmitt, C.G. 1976. Summer birds of the San Juan Valley, New Mexico. New Mexico Ornith. Soc. Publ. No. 4.

Smith, D.R. tech. coord. 1975. Proceedings of the Symposium on Management of Forest and Range Habitats for Nongame Birds. U.S. Forest Serv. Gen. Tech. Rep. WO-1.

Smith, K.G. 1981. Canonical correlation analysis and its use in wildlife habitat studies. Pages 80-92 *in* D.E. Capen, ed. The use of multivariate statistics in studies of wildlife habitat. U.S. Dept. Agr. For. Serv., Gen. Tech. Rept. RM-87. 249 pp.

Stevens, L.E., B.T. Brown, J.M. Simpson, and R.R. Johnson. 1977. The importance of riparian habitat to migrating birds. pp. 156-164 *in* R.R. Johnson and D.A. Jones (tech coords.), Importance, Preservation, and Management of Riparian Habitats: a Symposium. Gen. Tech. Rep. RM-43. Rocky Mountain For. and Range Sta., Fort Collins, CO.

U.S. Dep. Agric. 1992. New Mexico Agricultural Statistics. New Mexico Agric. Stat. Serv.

Van Cleave, M. 1935. Vegetation changes in the Middle Rio Grande Conservancy District. Unpubl. M.S. Thesis, Univ. New Mexico, Albuquerque. 107 pp.

Warner, R.E., and K.M. Hendrix. eds. 1984. California Riparian Systems. Univ. of Calif. Press, Berkeley. 1,035 pp.

Research and management of soil, plant, animal, and human resources in the Middle Rio Grande Basin

Deborah M. Finch[1]

Abstract.—The Rocky Mountain Forest and Range Experiment Station initiated a research program in 1994 called, "Ecology, diversity, and sustainability of soil, plant, animal, and human resources of the Rio Grande Basin". This program is funded by an Ecosystem Management grant from Forest Service Research. Its mission focuses on the development and application of new knowledge to sustain ecological systems and human populations in the Middle Rio Grande Basin. Research studies emphasize upland ecology and management, linkages between watersheds and riparian zones, sensitive fish and wildlife populations and species of concern, and past and present cultural resources.

INTRODUCTION

The Rocky Mountain Forest and Range Experiment Station (RMS) of the USDA Forest Service initiated a research program in 1994 on "Ecology, Diversity, and Sustainability of Soil, Plant, Animal, and Human resources of the Rio Grande Basin" (Finch and Tainter 1995a). Research focuses on the middle Basin, defined as the segment of the Rio Grande between Cochiti and Elephant Butte Reservoir, New Mexico (Finch and Tainter 1995b). The mission of the program is to develop, synthesize, and apply new knowledge on processes, interactions, and sociocultural uses of upland and riparian ecological systems for sustaining diverse, productive, and healthy plant, animal, and human populations and associated natural resources in the Middle Rio Grande Basin.

Research studies have been implemented to address four problem areas of this temporary Research Work Unit (RM-RWU-4652). Problem analyses for each of the four focus areas were completed and published as Chapters 1-9 of the General Technical Report, *Ecology, Diversity, and Sustainability of the Middle Rio Grande Basin* (Finch and Tainter 1995a). The four problem areas are:

1. Short-term and long-term responses of upland soils, water, nutrients, belowground systems, and vegetation to historic and current perturbations caused by factors such as climate, grazing, and fire, including interpretation of how such responses influence dynamics, stability, and productivity of upland ecosystems (Loftin et al. 1995, Gottfried et al. 1995, Klopatek 1995);
2. Processes within fluvial ecosystems that form major linkages between upland catchments (watersheds), the Rio Grande, and its floodplain bosques (Fox et al. 1995);
3. Responses of plant, fish and wildlife species to barriers in dispersal, migration, and reproduction along the Rio Grande and selected tributaries, including identification of species of concern and development of methods for recovering populations and habitats (Finch et al. 1995, Rinne and Platania 1995); and
4. Improving understanding of the environmental history of the Rio Grande Basin (Scurlock 1995a, 1995b), the historic and contemporary

[1] Project Leader, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, 2205 Columbia SE, Albuquerque, NM 87106.

human role in Basin ecosystems (Wozniak 1995), the nature and extent of anthropogenic disturbances to the Basin, and the sustainability of cultural diversity in the Basin (Finch and Tainter 1995b).

Rocky Mountain Station (RMS) scientists from Albuquerque, New Mexico, Flagstaff, Arizona, and Fort Collins, Colorado are participating in the program, representing disciplines such as anthropology, wildlife biology, fisheries biology, soil science, plant ecology, range science, forestry, and microbiology. Cooperators external to the Rocky Mountain Station include researchers from the following institutions:

- Sevilleta Long Term Ecological Research Site (LTER) and Department of Biology, University of New Mexico (UNM);
- Laboratory of Tree Ring Research, University of Arizona;
- National Biological Survey,
- Rio Grande Bird Research, Inc.,
- Southwest Region, U.S. Forest Service;
- Wingswept Research, Inc.;
- Desert Laboratory, U.S. Geological Survey;
- UNM Natural Heritage Program, and
- Fish and Wildlife Cooperative Unit, Oklahoma State University.

Additionally, partnerships have been developed with the following organizations who have provided study site access, housing, matching funds, equipment, vehicles, and expertise:

- Cibola, Santa Fe, and Carson National Forests,
- U.S. Fish and Wildlife Service, Region 2,
- Bureau of Land Management,
- Albuquerque Corps of Engineers,
- City of Albuquerque,
- Bosque del Apache Wildlife Refuge,
- Open Space Commission, Albuquerque,
- Rio Grande Nature Center,
- New Mexico Department of Game and Fish,
- New Mexico Partners in Flight,
- Bandelier National Monument, and
- Reio Grande Basin Consortium.

Recent accomplishments include participation in the Riparian Symposium that resulted in this proceedings. In particular, program participants gave papers, posters, and panels during a full day of the symposium devoted to "Rio Grande Basin Ecology and Management". Twelve papers prepared by RMS scientists and external cooperators of RM-RWU-4652 were published in the symposium proceedings. Accomplishments in Fiscal Year (FY) 1995 include completion of the GTR on the Middle Rio Grande Basin; about 40 presentations (e.g., invited talks, slide shows, posters, and field demonstrations) by team members on program research; team member participation in annual meetings and symposia of professional societies and groups such as The Wildlife Society, the Ecological Society of America, the North American Benthological Society, the Cooper Ornithological Society, International Rangeland Congress, and the Interior West Global Change Workshop, to name a few. RWU-4652 Team Leader Deborah Finch was elected Chair of the Rio Grande Basin Consortium, a coalition of agencies and organizations interested in developing methods and projects for sustaining Rio Grande Basin environments (for more information, see Potter and Finch, this issue). Consortium activities have been integrated with research program objectives where possible.

The next section describes research studies initiated under and funded by this umbrella program.

PROBLEM 1: UPLAND ECOSYSTEMS

Ecology and restoration of upland basin rangelands

Successful restoration of grassland ecosystems that have been damaged by disturbances such as historic overgrazing, drought, road-building, or recreation often involve intervention with treatments that will interrupt the desertification process and re-establish natural ecological processes. Current studies are assessing responses of soil nutrients, water, belowground ecosystems, and herbaceous plants to restoration treatments, and developing and evaluating various methodologies that can be used to successfully repair damaged grasslands invaded by woody and weedy species.

Experimental studies by Principal Investigators (PI) Dale Brockway and Samuel Loftin, RMS, Albuquerque, New Mexico, and Carole Klopatek, RMS, Tempe, Arizona were initiated in FYs 1994 and 1995 to assess the restoration benefits and success of prescribed fire and/or thinning of woody plants in blue grama grasslands, transition zones, and pinyon-juniper woodlands that are either protected from grazing (Sevilleta LTER) or are heavily grazed and showing signs of stress (e.g, high erosion, loss of ground cover, gullying). Study plans have been completed and approved for three studies, and experimental plots have been installed. Pre-treatment data were gathered in FY 1995 for the prescribed fire and thin/slash studies, and a 2nd year's data were collected for a slash mulch study on the Santa Fe National Forest. Loftin et al. (1995) and Klopatek (1995) describe research needs in shrub-invaded and belowground ecosystems in more depth in Chapters 6 and 9 of the Rio Grande GTR.

A final report was completed and approved for Cooperative Agreement 28-C4-799 (PI Carl White, UNM) evaluating nutrient cycling, soil moisture dynamics, and plant community ecology associated with historic cobblemulch gardens built by American Indians. This study included an experiment to determine the value of cobblemulch in restoring rangeland conditions. Manuscripts are under preparation.

Rangeland/woodland ecotonal responses to climate change

Studies of effects of climate change on pinyon-juniper woodlands and associated ecotones are underway through two cooperative agreements, No. 28-C4-800 with University of Arizona's (UA) Laboratory of Tree Ring Analysis (PIs Thomas Swetnam, UA, Julio Betancourt, U.S. Geological Survey, Desert Laboratory, and Gerald Gottfried, RMS, Flagstaff, Arizona) and No. 28-C4-860 with UNM (PI Bruce Milne, UNM Department of Biology and Sevilleta LTER). In its second year, the UA study is assessing masting, demography, and condition of pinyon by analyzing tree rings and then relating age structure, mortality, and recruitment rates to historical climate change (also, see Betancourt et al. 1993). The UNM study is evaluating boundary shifts in pinyon-juniper woodlands at landscape and regional scales in response to historic climate change. Both studies will provide information on factors contributing to woodland invasion and recession at the local and landscape levels. Such information is essential for interpreting condition and health of pinyon-juniper woodlands and corresponding ecotones. These studies will supply a scientific basis for prioritizing approaches to manage or restore rangelands and pinyon-juniper woodlands. Gottfried et al. (1995) describe the value of this kind of research in depth.

Research natural areas in the Middle Rio Grande Basin

The following studies on Research Natural Areas (RNA) were funded by matching RNA and RWU 4652 dollars under Cooperative Agreement 28-C4-807. Mesita de los Ladrones RNA, a remote, 700 ha mesa-top on the Santa Fe National Forest, supports a pinyon-juniper woodland that has been excluded from grazing, woodcutting and fire for at least 100 years. PIs Esteban Muldavin and Juanita Ladyman, UNM Natural Heritage Program, predicted a fine grain pattern of herbaceous plant species in a protected pinyon-juniper RNA. To evaluate spatial pattern and association of herbaceous species, 750 contiguous 25 x 50 cm quadrats were established along two replicate transects through the RNA. Sliding window analysis revealed relatively sharp boundaries between C4 and C3 grass-dominated communities related to subtle soil and topographic changes. Within the C4 communities, fine grain patch size ranged from 2.5 to 12 M among the seven species present with the exception of blue grama, the common dominant of disturbed woodlands, which exhibited no fine scale patch structure between 0.5 and 380 m. In C3 dominated communities large patches between 50 and 100 m were predominant. Spearman's rank correlations indicated moderate to strong negative correlations among the major grass dominants of these ecosystems. Results were presented at the International Association of Vegetation Science Symposium, Rice University, June 5, 1995.

A second study under Cooperative Agreement 28-C4-807 is evaluating age structure and density of an old growth ponderosa pine forest in relation to changes in fire regime and climate fluctuations. Monument Canyon RNA in the Jemez Mountains,

Santa Fe National Forest, has been protected from logging, fire, and grazing since the turn of the century. Study results show that forest age structure is distinctively multi-modal with a remnant overstory of older trees (>300 years) that are dead or dying. The understory is dominated by very dense pole stands in excess of 5,954 stems/ha. A 300+ yr fire history chronology developed for the stand shows that changes in stand structure are correlated with changes in fire regime with consequent impacts on recruitment. Recruitment may reflect specific climatic pulses leading to high density, even-aged cohorts that lack thinning or removal by fire. High density in the understory is suggested to have negative impacts on nutrient cycling and moisture competition which are increasing the rate of overstory mortality, leading to a different kind of old growth forest that would have been expected under pre-settlement conditions. These results were reported by Esteban Muldavin, Thomas Swetnam, and Mary Stuever at the Ecological Society of America's annual meeting, Snowbird, Utah, August, 1995.

A literature review on the role of cryptogamic crusts in pinyon-juniper woodlands located in RNAs was completed under Cooperative Agreement 28-C4-807, also. A draft manuscript was submitted to RWU 4652 in February 1995 by Juanita Ladyman and Esteban Muldavin, peer reviews were solicited, and the manuscript is currently under revision.

Species of concern in upland woodlands

Summer 1995 was the first field season for a study examining population status, species composition, abundance, and maternity roost requirements of threatened, endangered, and sensitive bats captured in pinyon-juniper habitats of the Middle Rio Grande Basin. Ten sites distributed across five mountain ranges of the Cibola National Forest were netted four times throughout the summer. Nets were placed over permanent water sources where bats often feed or drink in the course of a night. Number of species and total numbers of bats captured were highly variable at any one site, ranging from 0-11 species/site and 0-134 bats/night.

Radiotransmitters were placed on reproductive females of three Category 2 candidate species (*Myotis volans*, *Myotis thysanodes*, and *Myotis evotis*) and efforts were made to relocate the females in their maternity roosts after release. Five of the radiotagged bats were relocated and found colony-roosting in trees, most of which were ponderosa pine snags or broken tops with long vertical cracks (most likely caused by lightning strikes). Colony size varied from 30 to 200 maternal bats per roost. Problem analyses on bats and other upland species were incorporated into two chapters, pinyon-juniper woodlands (Gottfried et al. 1995) and grassland/shrubland ecosystems (Loftin et al. 1995), of the 1995 Rio Grande GTR. Preliminary data on bats were presented in a poster at the Riparian Symposium in Albuquerque, Sept. 1995, and results are published (Alice Chung-MacCoubrey this issue).

PROBLEM 2: WATERSHED ANALYSIS AND STREAM QUALITY

A problem analysis on climatic influences, hydrological processes, and watershed management in the middle Rio Grande Basin was published as Chapter 4 of the Rio Grande GTR (Fox et al. 1995). Chapter authors are actively pursuing research under Problem 2 of the Rio Grande Program, with emphasis on water and stream quality, nutrient dynamics, and vegetative cover in the Rio Puerco Watershed. The Rio Puerco is a major tributary of the Rio Grande and one that scientists and managers concur has been heavily damaged by historic livestock grazing. The Rio Puerco is estimated to contribute 40% of the non-point source pollution found in the Rio Grande. A University New Mexico class project that reported strategies to address nonpoint source pollution in Bear Canyon Watershed was also financially supported by RM-RWU-4652 (Roth et al. 1994).

Lightning and precipitation study

Deborah Potter, a U.S. Forest Service physical scientist in the Southwest Region's Watershed and Air Staff Group, was detailed to RM-RWU-4652 in FY 1994 to complete a Ph.D. dissertation at UNM on spatial relationships among lightning, precipitation, and vegetative cover within the Rio Puerco watershed of the middle Rio Grande Basin. The

study site is a 110 km^2 area that includes Pole Canyon and Prop Canyon, Cibola National Forest. To test the hypothesis that areas receiving equivalent amounts of precipitation during the monsoon season have similar vegetation responses, remotely-sensed lightning data from Direction Finders Network, Boise Interagency Fire Center, and vegetative data from the Cibola National Forest Terrestrial Ecosystem Survey are being compiled and analyzed. Final products will include GIS thematic maps of the study area that display precipitation and vegetative cover, and also precipitation contour maps. This work is funded by Cooperative Agreement No. 28-C4-810 between RM-RWU-4652 and Department of Biology, UNM. Two progress reports have been completed and approved, and a first chapter of the dissertation is published in this proceedings (Potter and Gorman this issue).

Rio Señorito nutrient dynamics study

A study of the effects of livestock grazing on nutrient dynamics was initiated on the Rio Señorito, a small tributary of the Rio Puerco in northcentral New Mexico where the Bureau of Land Management has constructed three 600-m grazing exclosures separated by 200-m gaps. This study is funded by Cooperative Agreement No. 28-C4-833 between RM-RWU-4652 and UNM (PI Maurice Valett, UNM Department of Biology). As anticipated, no statistical differences were found in nutrient concentrations of ice-covered surface water and ground water between grazed and ungrazed plots during winter. Data suggest phosphorous limitation of primary production. During spring runoff NO3-N concentrations were elevated in surface water. Preliminary results indicate a stream with high organic carbon content, metabolically active sediments and microbially-mediated nutrient dynamics that vary with hydrologic conditions.

Future goals are to survey the hydrology of the study reaches and compare nutrient retention in gaps and exclosures using tracer experiments. Higher rates of biological activity in segments protected from livestock and ore efficient cycling of N and P are hypothesized in these communities. Sewards and Valett (this issue) present preliminary results in this proceedings.

Roads and geomorphic controls in the Zuni Mountains

The objectives of this study are to determine the relationships between subsurface geomorphic features and the locations of riparian and wetland ecosystems along forest roads in the Zuni Mountains on the Cibola National Forest near Grants, New Mexico, and to evaluate the effects of road modification and construction activities planned for these forest roads. Investigators will be able to assess present conditions, make recommendations to the road engineers and then monitor changes that may take place following road construction and or other modifications. Ground Penetrating Radar (GPR) in conjunction with soil and vegetation surveys will be used to assess ecosystem conditions in selected study areas along Forest Roads 49 and 50 in the Zuni Mountains. Permanent transects and sampling points were established before road modifications began so that ecosystem changes in response to road activities could be monitored and documented. PIs include Daniel Neary and Roy Jemison, RMS, Flagstaff, Arizona; Dale Brockway, RMS, Albuquerque, New Mexico; and Phillip Guertin, Watershed Hydrology Department, University of Arizona.

PROBLEM 3: RIPARIAN SPECIES OF CONCERN

Stopover ecology of neotropical migratory birds

The Rio Grande is an important flyway for neotropical migratory birds, but its "bosque" has changed greatly over the past 100 years owing to exotic woody plant invasions, dams and diversion structures, urban expansion, water pollution, irrigation practices, agricultural conversion, and flood control. Finch et al. (1995) review research needs for Rio Grande bosque habitats, including habitat relationships of birds and arthropods. Our bird migration study assesses use and availability of stopover habitat for neotropical migratory landbirds during their north-south migration. Birds were captured in mist nets, measured, banded, and released in the spring and fall at the Bosque del Apache Wildlife Refuge and the Rio

Grande Nature Center, Albuquerque. Capture/recapture records provide an index to migration volume and timing, length of stopover, population status, and body condition and health, by species, sex, and age. To assess the value of different stopover habitats, point counts of migrating birds were conducted in native cottonwood-willow, exotic salt cedar, exotic Russian olive, and agricultural fields. Preliminary results are reported by Wang and Finch (this issue).

Arthropod populations and bird foraging behavior were also sampled along count routes. With Army Corps funds, vegetation types on the middle Rio Grande mapped in 1984 are being remapped to determine habitat change over a ten-year period (Mount et al. this issue). Research findings will be used to define methods, localities, and benefits for restoring migratory songbird habitats in the Rio Grande bosque. Bird and bosque studies are coordinated by PIs Deborah Finch, Project Leader, RMS, and Wang Yong, Visiting Scientist, RMS, and include two cooperative agreements, one on bird migration (28-C3-751, University of Southern Mississippi, Frank Moore and Wang Yong) and one on bird and arthropod interactions (28-C4-814, PIs Clifford Crawford and Mary J. Mund, UNM Department of Biology). Seven oral presentations and two posters were given on aspects of this integrated research, two papers were published including one by Wang and Finch in this proceedings, and four are in press.

Cowbirds and the Southwestern Willow Flycatcher

The Southwestern Willow Flycatcher (*Empidonax traillii exigua*) was federally listed as Endangered in March 1995. Declines in its population are associated with loss and conversion of its native shrub willow habitat, loss of backwater ponds due to flood control, invasion of exotic woody plants, and cowbird parasitism. Although the population status, parasitism rates, and general role of the brown-headed cowbird (*Molothrus ater*) in New Mexico are barely known, federal and state agencies have already advocated cowbird control measures as a step to recover willow flycatcher populations. To provide a scientific basis for flycatcher recovery in relation to cowbirds, a comprehensive literature review was conducted in FY 1994-95 assessing the relationships between cowbirds, hosts, and riparian habitat use in New Mexico, with emphasis on the flycatcher. This work is funded by Cooperative Agreement 28-C4-853 between RWU-4652 and Oklahoma State University. One oral presentation and one poster were given in FY 1995, and a paper is published in this proceedings (Schweitzer et al. this issue).

Fish species of concern

A problem analysis on fish species of concern in the Rio Grande Basin was completed and published in the Rio Grande GTR (Rinne and Platania 1995), and a chapter on the Rio Grande cutthroat trout was published in the Cutthroat Trout Conservation Assessment (Rinne 1995). John Rinne, RMS, Flagstaff, Arizona, and Robert Calamusso, New Mexico State University, are the leads for this research. Studies were initiated in FY 1994 to update current knowledge on the distribution of the Rio Grande cutthroat trout, a sensitive species formerly abundant in the headwaters of the Rio Grande in Colorado and northern New Mexico, and its co-occurrence with two native cyprinids, the Rio Grande sucker, a fish listed by the State of Colorado, and the Rio Grande chub (Calamusso and Rinne this issue).

The Rio Grande cutthroat trout was found to co-occur with the Rio Grande sucker on 1 creek on the Carson National Forest and 4 creeks on the Santa Fe National Forest. It co-occurred with the Rio Grande chub on 4 Carson National Forest creeks. All three species co-existed in Clear Creek, American Creek, and Rito de las Palomas on the Santa Fe National Forest. Seven new locations on the Carson National Forest were added to the distribution records of the Rio Grande cutthroat trout. Future objectives are to identify the role of physical and biological factors in fragmenting the distribution of these fish.

PROBLEM 4: HUMAN DIMENSIONS

Environmental history

A comprehensive environmental history and climatological review is under preparation by Dan Scurlock, Wingswept Research, Inc., under con-

tract RM-28-JV4-795. A preliminary history of the Middle Rio Grande Basin is presented in the Rio Grande GTR (Scurlock 1995a) and in a Global Change publication (Scurlock 1995b). Scurlock's study reveals major impacts on and changes to Middle Basin ecosystems over the past 450 years, since European entry into the region. Various land uses, such as grazing, intensive irrigation agriculture, logging, and construction of flood control features, combined with climatic fluctuations, have produced adverse changes in stream flow-morphology, ground water levels, topsoils, biotic communities, and individual plant and animal species. Indigenous human populations have been affected by these modifications also. Continued land-water use impacts from a rapidly increasing regional population suggest ongoing changes and major challenges for natural and human resource management organizations.

Human ecology and cultural resources

A specific review and problem analysis of the ecology and role of humans in the middle Rio Grande Basin was completed by Frank Wozniak, Forest Service Archaeological Consultant and published in the Rio Grande GTR (Wozniak 1995). According to this study, available technology and levels of technological knowledge have profoundly influenced human-generated impacts in both riparian and upland ecosystems. Understanding these impacts includes research on the influence of intensive irrigation agriculture introduced by the Spanish in the seventeenth century and the building of railroads by the Anglo-Americans in the nineteenth century. Research into the impacts of introduced domesticated plants and animals, especially cattle and sheep, over the past 450 years is also crucial to understanding the present-day ecosystems of the Basin.

As an adjunct to this research, the Rocky Mountain Station will publish a revised and updated version of a comprehensive document and literature review of irrigation in the Rio Grande Valley from prehistoric times to the present, conducted by Wozniak. This project will be undertaken during 1996.

Several papers on human dimensions research in the middle Rio Grande Basin were presented by RMS scientists and cooperators at the Riparian Symposium. Included were presentations on "human impacts on riparian ecosystems" (Wozniak this issue); "riverine settlement in the evolution of prehistoric land-use systems" (Tainter and Bagley Tainter this issue); "historic land use and grazing patterns" (Raish this issue) and "cobble mulch gardens" (Periman this issue). Raish and Periman also arranged a panel on the human role in shaping riparian ecosystems at the Riparian Symposium. The panel presentations, as well as the previously mentioned papers, are published in this proceedings. Joseph Tainter also presented a talk on Rio Grande Basin riverine settlement at The Wildlife Society's 2nd Annual Conference in Portland, OR, September 12-17, 1995.

A paper concerning resource conflict among the three primary ethnic groups resident in the Basin (American Indians, Hispanos, and Anglos) was presented by Raish at a conference on environmental dimensions of cultural conflict, organized by Tainter, RMS Project Leader, Cultural Heritage Research Work Unit, Albuquerque, and Brian Ferguson, Rutgers University. This research will be published in the issue resulting from the conference and will form a background to a future RMS study of the role of cultural differences in the perception of sustainability and sustainable resource use. Plans for development of this project are currently underway with anticipated completion of the research design and study plan in early 1996.

LITERATURE CITED

Betancourt, J.L.; Pierson, E.A.; Rylander, K. Aasen; Fairchild-Parks, J.A.; Dean, J.S. 1993. Influence of history and climate on New Mexico Pinyon-Juniper woodlands. Pp. 42-62 in Managing pinon-juniper ecosystems for sustainability and social needs. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-236.

Finch, D.M.; Tainter, J.A. 1995a. Ecology, diversity, and sustainability of the Middle Rio Grande Basin. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-268. 185 p.

Finch D.M.; Tainter, J.A., eds. 1995b. Introduction: Ecosystem research in a human context. Pp. 1-11 in Finch, D.M. and Tainter, J.A., eds., Ecology, diversity, and sustainability of the Middle Rio Grande Basin. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-268.

Finch, D.M.; Wolters, G.L.; Wang, Y.; Mund, M.J. 1995. Chapter 7. Plants, arthropods, and birds of the Rio Grande. Pp. 133-164 in Finch, D.M. and Tainter, J.A., eds., Ecology, diversity, and sustainability of the Middle Rio Grande Basin. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-268.

Fox, D.G.; Jemison, R.; Potter, D.U.; Valett, M.; Watts, R. 1995. Chapter 4. Geology, climate, land, and water quality. Pp. 52-79 in Finch, D.M. and Tainter, J.A., eds., Ecology, diversity, and sustainability of the Middle Rio Grande Basin. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-268.

Gottfried, G.J; Swetnam, T.W.; Allen, C.D.; Betancourt, J.L.; Chung-MacCoubrey, A. 1995. Chapter 5. Pinyon-juniper woodlands. Pp. 95-132 in Finch, D.M. and Tainter, J.A., eds., Ecology, diversity, and sustainability of the Middle Rio Grande Basin. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-268.

Klopatek, C.C. 1995. Chapter 9. Belowground ecosystems. Pp. 175-185 in Finch, D.M. and Tainter, J.A., eds., Ecology, diversity, and sustainability of the Middle Rio Grande Basin. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-268.

Loftin, S.R.; Chung-MacCoubrey, A; Aguilar, R.; Robbie, W. 1995. Chapter 6. Desert grassland and shrubland ecosystems. Pp. 80-94 in Finch, D.M. and Tainter, J.A., eds., Ecology, diversity, and sustainability of the Middle Rio Grande Basin. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-268.

Rinne, J.N. 1995. Chapter 3. Rio Grande cutthroat trout. Pp. 24-27 in Young, M., ed., Conservation Assessment for Inland Cutthroat Trout. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-256.

Rinne, J.N.; Platania, S.P. 1995. Chapter 8. Fish fauna. Pp. 165-174 in Finch, D.M. and Tainter, J.A., eds., Ecology, diversity, and sustainability of the Middle Rio Grande Basin. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-268.

Roth, F.; Bender, R.; Smith, G. 1994. Bear Canyon watershed - strategies to address nonpoint source pollution. University of New Mexico, Albuquerque, NM. 83 pp.

Scurlock, D. 1995a. Chapter 1. Environmental history. Pp. 12-28 in Finch, D.M. and Tainter, J.A., eds., Ecology, diversity, and sustainability of the Middle Rio Grande Basin. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-268.

Scurlock, D. 1995b. Historic interrelationships of humans and the ecosystems of the Middle Rio Grande Basin. Pp. 27-33 in Tinus, R.W., tech. ed., Proceedings of the Interior West Global Change Workshop. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-262.

Sewards, M.A.; Valett, H.M. 1996. Effects of livestock grazing on nutrient retention in a headwater stream of the Rio Puerco Basin In USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report, Fort Collins, CO, this issue.

Wozniak, F.E. 1995. Chapter 2. Human ecology and ethnology. Pp. 29-51 in Finch, D.M. and Tainter, J.A., eds., Ecology, diversity, and sustainability of the Middle Rio Grande Basin. U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. General Technical Report RM-268.

Landbird species composition and relative abundance during migration along the Middle Rio Grande

Wang Yong[1] and Deborah M. Finch[2]

Abstract.—In this paper, we report species composition and relative abundances of stopover migrants during spring and fall migration along the middle Rio Grande in 1994. We recorded 157 landbird species using mist-netting and survey methods at two sites on the Rio Grande, the Bosque del Apache and the Rio Grande Nature Center. A total of 6,509 birds was captured during spring and fall migrations at these sites. Of 157 species, 47% were neotropical long-distance migrants, 50% were short-distance migrants, and the remaining 3% were residents or border migrants. Comparisons of relative abundance from our 1994 field research to similar findings from studies conducted in 1981-83 and 1987-90 demonstrated that populations of many species have remained relatively stable over approximately 6 and 12 year periods, while some species have become more common or rare. Research recommendations focusing on bird use of stopover habitats during migration along the Rio Grande are provided.

INTRODUCTION

Narrow belts of riparian vegetation along ephemeral, intermittent, and perennial streams and rivers are most visible in shrubsteppe, grassland, and desert regions of the western United States where they comprise less than 1% of the landscape (Ohmart 1994). Yet, riparian habitats in arid and semiarid environments are unique reservoirs for biological diversity, including diversity of migratory animals. North and south travel along major waterways is characteristic of migratory birds that nest in North America. River corridors may be more important to migrating birds in desert regions of North America than in humid, more heavily vegetated areas (Wauer 1977). During spring and fall migration, riparian habitats can attract more than ten times the number of migratory birds compared to surrounding upland sites (Stevens et al. 1977; Hehnke and Stone 1979; Hink and Ohmart 1984). The riparian habitats along the Rio Grande are potential stopover sites for migratory landbirds that use the great Plains-Rocky Mountain "flight route" (Ligon 1961; Lincoln 1979). The availability of food, water, cover, and suitable north-south routing along this major aridland river may influence survival and guide migration of landbirds (Ligon 1961; Stevens et al. 1977; Wauer 1977; Finch 1991).

Human use of water for irrigation and consumption, and human use of land for agriculture, urban development, livestock grazing, and recreation have greatly altered riparian habitats in the Southwest (Tellman et al. 1993; Ohmart 1994; Finch et al. 1995). In Arizona and New Mexico, 90% of native

[1] *Visiting Wildlife Ecologist, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Albuquerque, NM 87106, arranged through a cooperative agreement with University of Southern Mississippi's Department of Biology.*

[2] *Project Leader and Research Wildlife Biologist, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Albuquerque, NM 87106.*

riparian ecosystems are estimated to have been eliminated, and 83% of remaining riparian areas managed by the U.S. Bureau of Land Management are reported to be in unsatisfactory condition (Almand and Krohn 1979). Noss et al. (1995) lists riparian woodlands in California, Arizona and New Mexico as "endangered ecosystems". How changes in riparian habitats along the Rio Grande have affected long-term or short-term migration patterns, population numbers, and survival of migratory landbirds are unclear. Effective conservation strategies for neotropical and short-distance migratory landbirds cannot be established without basic information about the importance of riparian corridors as stopover habitat during migration.

In spring 1994, we initiated a study to investigate use of riparian habitats along the middle Rio Grande by neotropical and short-distance landbird migrants during fall and spring migration. Here, we report species composition and relative abundance of stopover migratory landbirds at two sites along the middle Rio Grande. We examined changes in relative abundance of landbird migrants by comparing our results with relative abundance data from previous studies. Based on this information, we provided recommendations for new research that will supply a sound basis for conserving migratory landbirds and riparian habitats along the middle Rio Grande.

METHODS

Study site

This study was conducted at two sites in the Middle Rio Grande Valley of New Mexico: Rio Grande Nature Center (RGNC, N 35°07' and W 106°41'), Bernalillo County, NM, and Bosque del Apache National Wildlife Refuge (BNWR, N33°48' and W106°52'), Socorro County, NM. The data were collected in spring from April 4 to June 15, and in fall from August 1 to November 13, 1994.

RGNC, a 270 acre stretch of bosque along the Rio Grande, lies within the city limits of Albuquerque. Rio Grande cottonwood (*Populus fremontii var. wislizeni*) with a Russian olive (*Elaeagnus angustifolia*) understory, and clumps of willow (*Salix spp.*) and saltcedar (*Tamarix chinensis*) form the major habitats. These are surrounded by agricultural lands and residential housing. The availability of suitable habitat at RGNC site is restricted in area and diversity because of urban development and human activities in the Albuquerque area. The 57,191 acre BNWR, located about 90 miles south of Albuquerque, was established in 1939 as a refuge and breeding grounds for migratory waterfowl and other wildlife. We identified five major habitat types at BNWR: cottonwood-willow, screwbean mesquite (*Prosopis pubescens*), saltcedar, agriculture land, and willow strips along the irrigation waterways. This floodplain vegetation is wider in area and less exposed to disturbance from human use than that at RCNC.

Survey counts

In spring 1994, we established six transects in the three dominant vegetation types at RGNC: cottonwood, mixed vegetation, and agriculture fields. At BNWR, we installed eight transects in the four dominant habitat types: cottonwood, saltcedar, screwbean mesquite, and agriculture fields. Two willow transects along the irrigation waterways were added at BNWR during the fall field season. All transects were at least 400 m apart. Each transect was 1 km long, and point count stations were located at 200 m intervals (6 stations/transect). It should be noted that although the transects were located based on dominant vegetation types, almost all transects contained various amounts of other vegetation. The transects were not standardized in orientation or linearity because of the patchy availability of the vegetation types.

Bird surveys were started about one half hour after sunrise and completed before 12:00 (MST). One transect in each habitat type was surveyed daily at BNWR and RGNC. To reduce bias due to variation in survey time, the order of visitation to habitat types was rotated. Birds seen or heard as transects were walked were recorded. Bird behavior and weather information were also noted. Observations were separated according to perpendicular distance from the transect: ≤ 25 m or > 25 m. All birds detected during surveys were used for this study.

Mist-netting operation

Migrants were captured (and recaptured) using nylon mist-nets (12 x 2.6 m with 30 mm or 36 mm

mesh). Twenty mist-nets were used at each site. Unless rain, high winds, or temperature dictated a change, mist-nets were opened 15 minutes before sunrise and operated approximately 6 hours each banding day.

Species, subspecies, age, and sex were identified by consulting Pyle et al. (1987), US Fish & Wildlife Service Bird Banding Manual (1984), and various field guides. Body mass of each captured individual was weighed to the nearest 0.1 g using a digital electronic balance (ACCULAB V-333). Morphological characteristics including unflattened wing chord, tarsus length, tail length, and molt condition were measured on each bird. Additional information such as feather length, wing span, and wing area were also collected for some species to assist in species identification and to meet other research goals. The amount of skull ossification was examined in fall to identify age. Each individual was banded with a National Biological Service aluminum leg band. Birds were released immediately after this process.

Classification of migration type and relative abundance

We evaluated species composition and relative abundance in relation to the migration distance of each species. Migratory distance was classified based on the Partners in Flight list (1992): (A) long-distance migrants (or neotropical migrants, species breeding in North America and wintering primarily south of the United States); (B) short-distance migrants (species breeding and wintering extensively in North America); (C) species breeding primarily south of the U.S./Mexican border but having populations that extend into the southwestern U.S.; and (D) permanent residents, species inhabiting sites year-round.

Hink and Ohmart (1984) conducted a three-year study of riparian habitats and associated terrestrial vertebrate communities of the Middle Rio Grande Valley from 1981 to 1983. The study provided the first available comprehensive data on landbird species composition and relative abundance in the middle Rio Grande. As a follow-up to Hink and Ohmart, and to assess bird population changes, Hoffman (1990) conducted avian surveys in the Middle Rio Grande Valley State Park from 1987 to 1990. To compare relative abundance data from our project with data from these two studies, we adopted relative abundance categories used by Hink and Ohmart (1984) and Hoffman (1990): abundant (very high density), common to fairly common (high to moderate density), uncommon (low density), and rare (very low density). Thus, abundant species can be readily observed during their migration, common to fairly common species should be seen fairly easily by most observers during migration; uncommon species may be seen with diligent searching, and rare species are much less predictable (some of these species are casual or accidental to the Middle Rio Grande). Similar classification systems for relative abundance of southwestern birds are used by other ornithologists (e.g., Hubbard 1978; Rosenberg et al. 1991).

RESULTS

Species composition

For the two sites combined, 157 species were recorded during mist-netting operation (108 species) and daily survey (43 additional species). Seventy-four species (47%) belonged to type A, Neotropical or long-distance migrants; 78 species (50%) were type B or short-distance migrants that breed and winter extensively in North America; 2 species (1%) were type C, Mexico/U.S. border species; and the remaining 3 species (2%) were residents or migrants not defined by the Partners in Flight list (Table 1, Fig. 1).

For the two sites combined, a total of 6,509 landbirds of 102 species were captured by mist-netting during spring and fall migrations (Table 1). During the 1994 spring migration, we banded 436 individuals of 50 species at RGNC and 421 individuals of 53 species at BNWR. During fall migration, 4,269 individuals of 77 species were captured at RGNC and 1,383 individuals of 55 species were banded at BNWR. The seasonal difference in numbers of birds captured was unusually large in some species. For example, a total of 877 Wilson's Warblers were captured during fall migration at the two study sites, while only 34 individuals of this species were captured during spring migration. An extreme example was Chipping Sparrow; while only 3 birds were captured during spring migration, 950 birds were captured during fall migration.

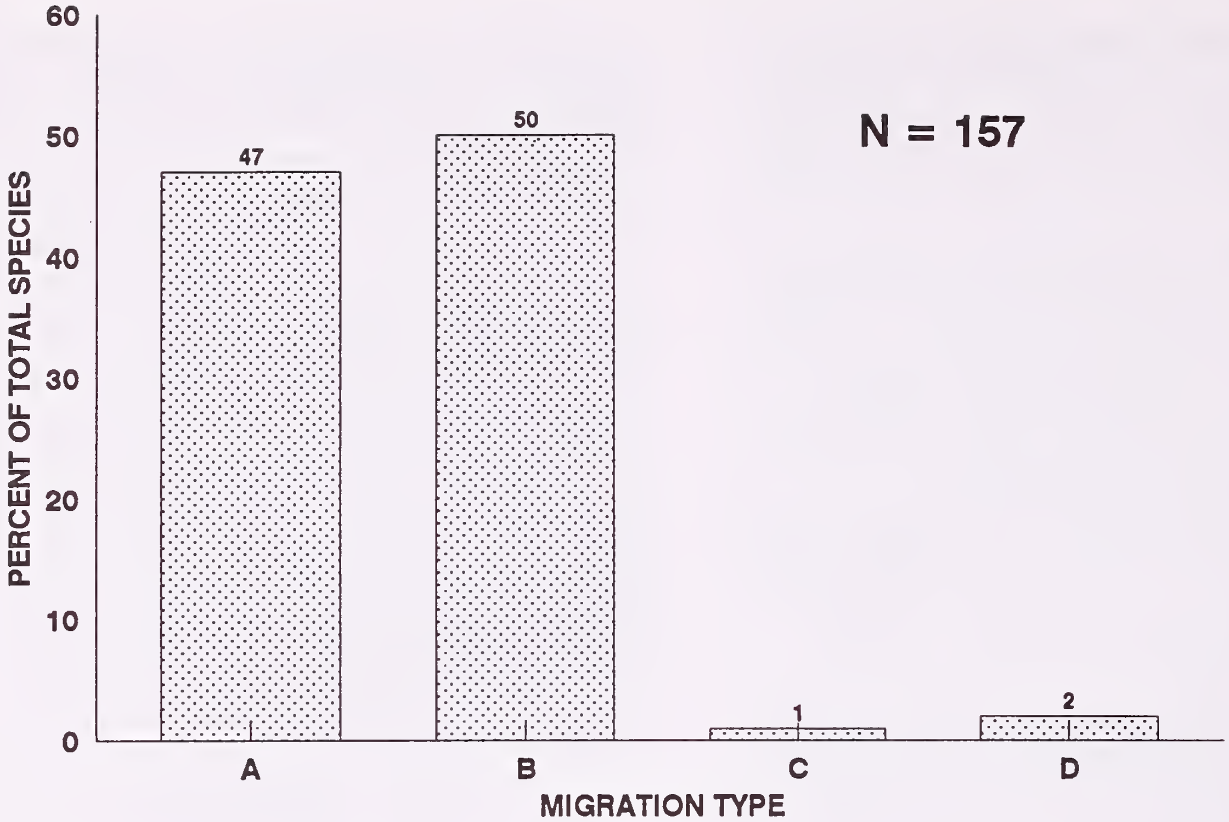


Figure 1—Migratory status of landbirds (N=157 species) detected along the middle Rio Grande during spring and fall migrations, 1994. A = neotropical migrants, B = short-distance migrants, C = species breeding along U.S./Mexico border, and D = permanent residents.

Table 1—Migratory distances (MD) and relative abundances of landbirds recorded in the middle Rio Grande Valley during studies by Yong and Finch (YF; this study), Hoffman (HF; 1990), and Hink and Ohmart (HK; 1984), and total number of mist-netting captures (N) at Bosque del Apache and Rio Grande Nature Center during spring and fall migrations, 1994.[1]

Common name	Scientific name[2]	MD	YF	HF	HK	N[3]
Cathartidae						
Turkey Vulture	*Cathartes aura*	*B*	*C*	*U*	*U*	
Accipitridae						
Osprey	*Pandion haliaetus*	*B*	*R*	*R*	*R*	
Northern Harrier	*Circus cyaneus*	*B*	*U*	*R*	*C*	
Sharp-shinned Hawk	*Accipiter striatus*	*B*	*U*	*U*	*U*	*3*
Cooper's Hawk	*Accipiter cooperii*	*B*	*C*	*U*	*C*	*1*
Northern Goshawk	*Accipiter gentilis*	*B*	*n*	*R*	*U*	
Red-tailed Hawk	*Buteo jamaicensis*	*B*	*C*	*U*	*C*	
Swainson's Hawk	*Buteo swainsoni*	*A*	*C*	*n*	*C*	
Ferruginous Hawk	*Buteo regalis*	*B*	*R*	*n*	*U*	
Falconidae						
American Kestrel	*Falco sparverius*	*B*	*C*	*U*	*C*	*2*
Phasianidae						
Scaled Quail	*Callipepla squamata*	*B*	*U*	*n*	*R*	
Gambel's Quail	*Callipepla gambelii*	*B*	*C*	*C*	*C*	
Ring-necked Pheasant	*Phasianus colchicus*	*B*	*C*	*U*	*C*	

(Cont'd.)

Table 1. Continued

Common name	Scientific name[2]	MD	YF	HF	HK	N[3]
Wild Turkey	*Meleagris gallopavo*	D	U	n	n	
Columbidae						
Rock Dove	*Columba livia*	B	C	U	C	
Mourning Dove	*Zenaida macroura*	B	A	R	A	4
Cuculidae						
Yellow-billed Cuckoo	*Coccyzus americanus*	A	U	R	U	6
Greater Roadrunner	*Geococcyx californianus*	B	C	C	C	
Strigidae						
Western Screech-owl	*Otus kennecotti*	B	U	n	U	
Great Horned Owl	*Bubo virginianus*	B	C	U	C	
Caprimulgidae						
Common Nighthawk	*Chordeiles minor*	A	U	R	C	
Trochilidae						
Black-chinned Hummingbird	*Archilochus alexandri*	A	A	A	A	
Broad-tailed Hummingbird	*Selasphorus platycercus*	A	C	U	C	
Rufous Hummingbird	*Selasphorus rufus*	A	C	U	C	
Calliope Hummingbird	*Stellula calliope*	A	R	n	C	
Alcedinidae						
Belted Kingfisher	*Ceryle alcyon*	B	C	U	C	3
Picidae						
Downy Woodpecker	*Picoides pubescens*	B	C	U	C	12
Hairy Woodpecker	*Picoides villosus*	B	R	R	R	4
Red-napped Sapsucker	*Sphyrapicus nuchalis*	B	U	n	U	1
Lewis' Woodpecker	*Melanerpes lewis*	B	U	n	U	
Northern Flicker	*Colaptes auratus*	B	C	C	C	16
Tyrannidae						
Olive-sided Flycatcher	*Contopus borealis*	A	U	R	C	4
Western Wood-Pewee	*Contopus sordidulus*	A	C	U	C	46
Willow Flycatcher	*Empidonax traillii*	A	U	R	C	22
Least Flycatcher	*Empidonax minimus*	A	R	n	R	1
Hammond's Flycatcher	*Empidonax hammondii*	A	R	n	R	6
Dusky Flycatcher	*Empidonax oberholseri*	A	C	n	C	92
Gray Flycatcher	*Empidonax wrightii*	A	U	n	U	27
Cordilleran Flycatcher	*Empidonax difficilis*	A	U	n	R	20
Black Phoebe	*Sayornis nigricans*	B	C	R	C	17
Say's Phoebe	*Sayornis saya*	B	C	R	C	4
Ash-throated Flycatcher	*Myiarchus cinerascens*	A	C	U	C	10
Brown-crested Flycatcher	*Myiarchus tyrannulus*	B	R	n	n	4
Western Kingbird	*Tyrannus verticalis*	A	C	R	C	6
Cassin's Kingbird	*Tyrannus vociferans*	A	R	n	R	
Alaudidae						
Horned Lark	*Eremophila alpestris*	B	U	R	U	
Hirundinidae						
Purple Martin	*Progne subis*	A	R	n	R	
Cliff Swallow	*Hirundo pyrrhonota*	A	U	U	C	
Barn Swallow	*Hirundo rustica*	A	A	C	C	
Tree Swallow	*Tachycineta bicolor*	B	U	U	U	
Violet-green Swallow	*Tachycineta thalassina*	A	C	C	C	1
Bank Swallow	*Riparia riparia*	A	U	R	U	

(Cont'd.)

Table 1. Continued

Common name	Scientific name[2]	MD	YF	HF	HK	N[3]
Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	A	C	U	C	9
Corvidae						
Blue Jay	*Cyanocitta cristata*	D	R	R	R	
Scrub Jay	*Aphelocoma coerulescens*	B	C	U	C	7
Common Raven	*Corvus corax*	B	U	R	C	
Chihuahuan Raven	*Corvus cryptoleucus*	B	R	n	R	
American Crow	*Corvus brachyrhynchos*	B	C	A	C	
Pinyon Jay	*Gymnorhinus cyanocephalus*	B	U	n	C	
Paridae						
Mountain Chickadee	*Parus gambelli*	B	U	U	R	6
Black-capped Chickadee	*Parus atricapillus*	B	C	C	U	11
Remizidae						
Verdin	*Auriparus flaviceps*	B	U	n	U	1
Aegithalidae						
Common Bushtit	*Psaltriparus minimus*	B	U	n	U	6
Sittidae						
Red-breasted Nuthatch	*Sitta canadensis*	B	R	R	R	3
White-breasted Nuthatch	*Sitta carolinensis*	B	C	U	U	12
Pygmy Nuthatch	*Sitta pygmaea*	B	R	n	R	
Certhiidae						
Brown Creeper	*Certhia americana*	B	R	U	R	
Troglodytidae						
Rock Wren	*Salpinctes obsoletus*	B	U	n	R	
Bewick's Wren	*Thryomanes bewickii*	B	C	U	C	47
House Wren	*Troglodytes aedon*	A	U	U	C	26
Marsh Wren	*Cistothorus palustris*	B	R	R	C	1
Muscicapidae						
Sylviinae						
Ruby-crowned Kinglet	*Regulus calendula*	B	C	U	C	190
Blue-gray Gnatcatcher	*Polioptila caerulea*	A	U	U	U	1
Turdinae						
Swainson's Thrush	*Catharus ustulatus*	A	R	R	R	2
Hermit Thrush	*Catharus guttatus*	B	C	U	C	74
American Robin	*Turdus migratorius*	B	A	A	C	62
Townsend's Solitaire	*Myadestes townsendi*	B	U	R	R	
Western Bluebird	*Sialia mexicana*	B	R	R	R	
Mountain Bluebird	*Sialia currucoides*	B	U	n	U	
Mimidae						
Gray Catbird	*Dumetella carolinensis*	A	R	R	C	2
Northern Mockingbird	*Mimus polyglottos*	B	U	R	C	1
Sage Thrasher	*Oreoscoptes montanus*	B	R	n	R	1
Crissal Thrasher	*Toxostoma dorsale*	B	R	n	U	
Motacillidae						
Water Pipit	*Anthus spinoletta*	B	U	R	U	
Bombycillidae						
Cedar Waxwing	*Bombycilla cedrorum*	B	C	U	C	

(Cont'd.)

Table 1. Continued

Common name	Scientific name[2]	MD	YF	HF	HK	N[3]
Ptilogonatidae						
Phainopepla	*Phainopepla nitens*	A	R	n	R	
Laniidae						
Loggerhead Shrike	*Lanius ludovicianus*	B	U	n	U	
Sturnidae						
European Starling	*Sturnus vulgaris*	B	A	A	C	2
Vireonidae						
Solitary Vireo	*Vireo solitarius*	A	C	R	U	12
Warbling Vireo	*Vireo gilvus*	A	C	C	C	28
Red-eyed Vireo	*Vireo olivaceous*	A	R	R	R	1
Yellow-throated Vireo	*Vireo flavifrons*	A	R	n	R	
Emberizidae						
Parulinae						
Orange-crowned Warbler	*Vermivora celata*	A	C	R	C	193
Nashville Warbler	*Vermivora ruficapilla*	A	R	n	R	1
Virginia Warbler	*Vermivora virginiae*	A	C	n	C	67
Lucy's Warbler	*Vermivora luciae*	C	R	n	R	4
Yellow Warbler	*Dendroica petechia*	A	C	R	C	97
Magnolia Warbler	*Dendroica magnolia*	A	R	n	R	1
Blackpoll Warbler	*Dendroica striata*	A	R	n	R	
Grace's Warbler	*Dendroica graciae*	A	R	n	R	
Yellow-rumped Warbler	*Dendroica coronata*	B	A	C	A	539
Black-throated Gray Warbler	*Dendroica nigrescens*	A	R	R	U	1
Townsend's Warbler	*Dendroica townsendi*	A	U	n	R	4
Palm Warbler	*Dendroica palmarum*	A	R	n	R	1
Black-and-white Warbler	*Mniotilta varia*	A	R	n	R	1
Northern Waterthrush	*Seiurus noveboracensis*	A	U	n	U	11
Ovenbird	*Seiurus aurocapillus*	A	R	n	R	
Kentucky Warbler	*Oporornis formosus*	A	R	n	R	1
Mourning Warbler	*Oporornis philadelphia*	A	R	n	n	1
MacGillivray's Warbler	*Oporornis tolmiei*	A	C	n	C	210
Common Yellowthroat	*Geothlypis trichas*	A	C	U	C	44
Wilson's Warbler	*Wilsonia pusilla*	A	A	C	A	911
Yellow-breasted Chat	*Icteria virens*	A	U	U	C	8
Thraupinae						
Summer Tanager	*Piranga rubra*	A	C	R	C	23
Western Tanager	*Piranga ludoviciana*	A	C	C	C	67
Cardinalinae						
Pyrrhuloxia	*Cardinalis sinuatus*	D	R	R	n	1
Rose-breasted Grosbeak	*Pheucticus ludovicianus*	A	R	n	R	1
Black-headed Grosbeak	*Pheucticus melanocephalus*	A	A	A	A	111
Blue Grosbeak	*Guiraca caerulea*	A	A	C	A	121
Lazuli Bunting	*Passerina amoena*	A	C	R	C	104
Indigo Bunting	*Passerina cyanea*	A	R	R	C	2
Painted Bunting	*Passerina ciris*	A	R	n	n	1
Dicksissel	*Spiza americana*	A	R	n	R	1
Emberizinae						
Green-tailed Towhee	*Pipilo chlorurus*	A	C	R	C	47
Rufous-sided Towhee	*Pipilo erythrophthalmus*	B	C	U	C	50
Brown Towhee	*Pipilo fuscus*	B	R	n	U	

(Cont'd.)

Table 1. Continued

Common name	Scientific name[2]	MD	YF	HF	HK	N[3]
Cassin's Sparrow	*Aimophila cassinii*	B	R	n	n	1
Chipping Sparrow	*Spizella passerina*	A	A	R	C	953
Clay-colored Sparrow	*Spizella pallida*	A	U	n	R	70
Brewer's Sparrow	*Spizella breweri*	A	C	n	C	149
Vesper Sparrow	*Pooecetes gramineus*	B	C	n	U	144
Lark Sparrow	*Chondestes grammacus*	A	C	n	C	167
Lark Bunting	*Calamospiza melanocorys*	A	R	n	R	6
Savannah Sparrow	*Passerculus sandwichensis*	B	C	n	C	118
Grasshopper Sparrow	*Ammodramus savannarum*	A	R	n	n	3
Song Sparrow	*Melospiza melodia*	B	C	A	C	135
Lincoln's Sparrow	*Melospiza lincolnii*	A	C	R	U	101
White-throated Sparrow	*Zonotrichia albicollis*	B	U	R	U	6
Golden-crowned Sparrow	*Zonotrichia atricapilla*	B	R	n	n	1
White-crowned Sparrow	*Zonotrichia leucophrys*	B	A	A	A	450
Dark-eyed Junco	*Junco hyemalis*	B	A	A	A	283
Icterinae						
Bobolink	*Dolichonyx oryzivorus*	A	R	n	R	
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	A	U	R	C	
Red-winged Blackbird	*Agelaius phoeniceus*	A	U	R	C	72
Western Meadowlark	*Sturnella neglecta*	B	A	C	A	2
Brewer's Blackbird	*Euphagus cyanocephalus*	B	U	U	C	
Common Grackle	*Quiscalus quisculus*	B	U	n	U	
Great-tailed Grackle	*Quiscalus mexicanus*	B	C	C	U	5
Brown-headed Cowbird	*Molothrus ater*	B	C	A	C	10
Orchard Oriole	*Icterus spurius*	A	R	n	R	2
Northern Oriole	*Icterus galbula*	A	C	U	U	35
Fringillidae						
House Finch	*Carpodacus mexicanus*	B	A	C	C	203
Pine Siskin	*Carduelis pinus*	B	C	C	C	15
Lesser Goldfinch	*Carduelis psaltria*	B	C	C	U	38
American Goldfinch	*Carduelis tristis*	B	C	U	C	97
Evening Grosbeak	*Coccothraustes vespertinus*	B	U	U	R	
Ploceidae						
House Sparrow	*Passer domesticus*	B	A	C	C	
Total						6,509

[1] MD = migratory distance (A = neotropical migrants, B = short-distance migrants, C = species breeding along U.S./Mexico border, and D = permanent residents; from list by Partners in Flight (1992). Columns YF, HF, and HK are relative abundances (R = rare, U = uncommon, C = common, A = abundant, n = not observed during given study).

[2] Common and scientific names are based on the A.O.U. Check-list of North American Birds (1983).

[3] N = number of mist-netting captures at combined sites in spring and fall, 1994. Species detected during transect surveys rather than with mist-nets were left blank.

Comparing combined spring and fall data between the two sites, more species and more individuals were captured at the RGNC site (4,705 individuals of 87 species) than at the BNWR site (1,804 individuals of 71 species). In general, more individuals of any given species were captured at RGNC. However, more individuals of the following species were caught at BNWR: Lucy's Warbler, Pyrrhuloxia, Summer Tanager, Verdin, Yellow-billed Cuckoo, Ruby-crowned Kinglet, Rufous-side Towhee, Yellow-breasted Chat, Western Wood-Pewee and Common Yellowthroat.

Some species that breed mostly in the eastern United State and are rare or otherwise unusual in the Middle Rio Grande Valley were captured in low numbers. These included Black-and-white Warbler, Dickcissel, Gray Catbird, Kentucky Warbler, Magnolia Warbler, Mourning Warbler, Nashville Warbler, Swainson*s Thrush, Painted Bunting, Orchard Oriole, Red-eyed Vireo, Rose-breasted Grosbeak, and White-throated Sparrow. Brown-crested Flycatcher, a species not previously reported in the Middle Rio Grande Valley, was captured at BNWR during both spring and fall migration seasons. Western Palm Warbler, a regular migrant along the Pacific Coast but rare in the interior Southwest, was captured at RGNC during spring migration. One Golden-crowned Sparrow, another regular Pacific Coast species that is rare in the Middle Rio Grande Valley was captured in fall at the RGNC. We captured several species such as Kentucky Warbler, Mourning Warbler, Swainson's Thrush, and Red-eyed Vireo that were not on the BNWR bird checklist. Others such as Magnolia Warbler, Palm Warbler, and Cassin's Sparrow were not on the RGNC bird checklist.

Two species of concern, Yellow-billed Cuckoo and Willow Flycatcher, were captured at banding stations. Four Yellow-billed Cuckoo were captured at BNWR in spring and two at BNWR in fall. A total of 22 Willow Flycatchers was captured at the two sites. Eight of these were captured during spring migration and 14 during fall migration. About 30% of these Willow Flycatchers were identified as the endangered Southwestern race (*Empidonax traillii extimus*) based on morphology measurements and body color (see Aldrich 1951; Unitt 1987; Hubbard 1987; Browning 1993 for identification criteria). Mean ($\pm$SD) capture dates for Willow Flycatchers in spring were May 15($\pm$5) at BNWR and May 30($\pm$11) at RGNC. In fall, mean capture dates were August 27($\pm$14) at RGNC and September 5($\pm$7) at BNWR.

Relative abundance

Of the 157 species detected, 14 (10%) were classified as abundant, 56 (36%) were common, 39 (25%) were uncommon, and 47 (30%) were rare (Table 1, Fig. 2). Of the 74 long-distance migratory species, 6 (8%) (Black-chinned Hummingbird, Barn Swallow, Wilson's Warbler, Black-headed Grosbeak, Blue Grosbeak, and Chipping Sparrow) were abundant; 39 (53%) were common to uncommon, and 29 species (39%) were rare. Among the 78 short distance migrants, 9 species (12%) were abundant, 55 species (71%) were common to uncommon, and 14 species (18%) were rare. While long-distance migratory species had more rare species, short-distance migratory species had more common and uncommon species (log-likelihood G = 8.69, df = 3, $\underline{P} < 0.05$).

The most commonly-captured species at RGNC were Chipping Sparrow (882 birds), Yellow-rumped Warbler (492), and Wilson's Warbler (484). These three species accounted for 39% of the total captures at the site. At BNWR, the most commonly-captured species, Wilson's Warbler (427), White-crowned Sparrow (159), and Ruby-crowned Kinglet (140), accounted for 40% of the total captures at the site. When captures from the two sites were combined, the most commonly-captured species were Chipping Sparrow (953 captures), Wilson's Warbler (911), Yellow-rumped Warbler (539), and White-crowned Sparrow (450). These four species made up 44% of total captures. Nineteen additional species comprised another 38% of the common captures. Arranged in decreasing abundance, these were Dark-eyed Junco (283), MacGillivray's Warbler (210), House Finch (203), Orange-crowned Warbler (193), Ruby-crowned Kinglet (190), Lark Sparrow (167), Brewer's Sparrow (149), Vesper Sparrow (144), Song Sparrow (135), Blue Grosbeak (121), Savannah Sparrow (118), Black-headed Grosbeak (111), Lazuli Bunting (104), Lincoln's Sparrow (101), American Goldfinch (97), Yellow Warbler (97), and Dusky Flycatcher (92).

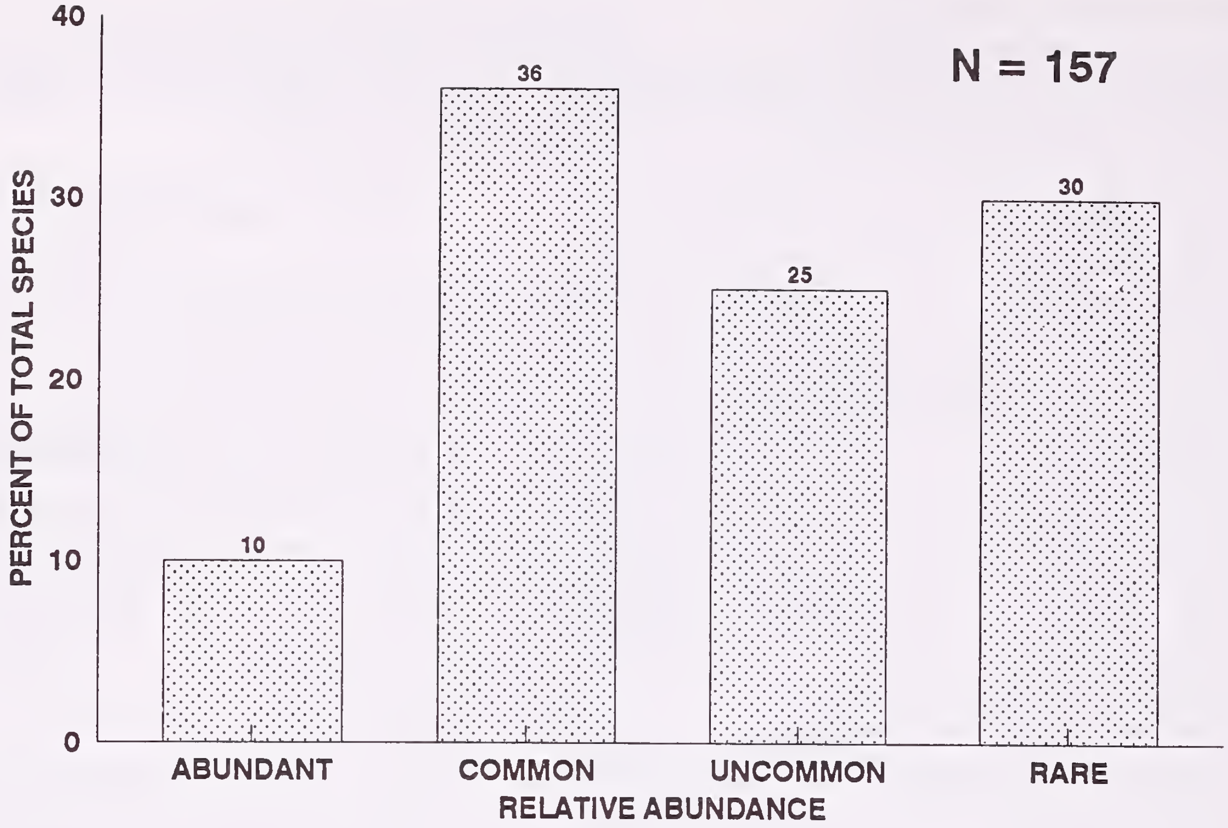


Figure 2—Relative abundance of landbirds (N=157 species) recorded in middle Rio Grande riparian habitats during spring and fall migrations, 1994.

Comparisons of relative abundance

We detected more species in migration along the Rio Grande during our 1994 spring and fall field seasons than were reported by Hink and Ohmart (1984) during their comprehensive three-year study. Relative abundances from our study corresponded significantly with abundance data from studies by both Hink and Ohmart (1984) (Log likelihood G = 173.67, df = 12, $\underline{P} < 0.001$) and Hoffman (1990) (Log likelihood G = 126.88, df = 12, $\underline{P} < 0.001$). The similarity of our abundance data with Hink/Ohmart's was greater than that with Hoffman's data. Hoffman, whose sampling localities were fewer than ours and were restricted to the Albuquerque area, reported only 98 of the 157 landbird species we observed. We detected seven additional species - Wild Turkey, Brown-crested Flycatcher, Grasshopper Sparrow, Golden-crowned Sparrow, Cassin's Sparrow, Painted Bunting, and Mourning Warbler - that were not recorded by either Hink and Ohmart or Hoffman. All these species were classified as rare and were only detected during our mist-netting operation with the exception of Wild Turkey which we observed during daily surveys and classified as uncommon. Of the seven new species, Painted Bunting and Mourning Warbler breed mostly in the East; Golden-crowned Sparrow breeds mostly along the Pacific Coast; and Brown-crested Flycatcher and Cassin's Sparrow have relatively restricted breeding distributions, mostly in the Southwest. Pyrrhuloxia, another rare species along the middle Rio Grande, was not detected during 1981-83 by Hink and Ohmart, but it was recorded by Hoffman and ourselves.

Relative abundances of Calliope Hummingbird, Olive-sided Flycatcher, Brewer's Sparrow, Indigo Bunting, Yellow-breasted Chat, Gray Catbird, and Marsh Wren were lower in 1994 (our study) than in the 80's (Hink and Ohmart 1984; Hoffman 1990). In contrast, relative abundances of Cordilleran Flycatcher, European Starling, Great-tailed Grackle, Chipping Sparrow, Black-capped Chickadee, Mountain Chickadee, and House Sparrow were higher in 1994 than in the previous decade.

DISCUSSION

Species composition and relative abundance

This study documents volume, relative abundance, and composition of migratory species in the middle Rio Grande Valley. We recorded seven additional species that Hink and Ohmart (1984) did not observe during their comprehensive study. The migrants detected during our study included summer residents such as Black-headed Grosbeak, Blue Grosbeak, Black-chinned Hummingbird, and Cordilleran Flycatcher that breed in the area and are present during late spring and summer; winter residents such as White-crowned Sparrow, Dark-eyed Junco, and Yellow-rumped Warbler that are present for varying lengths of time between September and April; and transient species such as most of the warblers and flycatchers that use the middle Rio Grande riparian habitats as stopover sites during spring and fall migration.

Not only were New Mexico breeding birds detected during their spring and fall migrations, but numerous species breeding in other western states and even several eastern species were also detected during this study. During fall migration, a large portion of Rio Grande migrants are young, hatching-year birds (Yong and Finch unpublished) thought to be especially vulnerable to navigational mistakes, starvation, and predation on their first journey south to the wintering grounds. We argue that disturbance (e.g., burning, bridges, recreation, urbanization, and grazing) and changes in habitat structure and plant species composition in the Rio Grande bosque will increase the probability that migration of some species will be altered or disrupted, and that such changes will affect not only local New Mexico birds but also populations from a much wider geographic region.

We suspect that the higher volume of migrants at the Rio Grande Nature Center site compared to the Bosque del Apache site is due to constriction of suitable Rio Grande habitat within the town of Albuquerque. Urban encroachment around the RGNC may cause migrants to be concentrated into a narrow and limited habitat corridor along the river itself. Likewise, Hink and Ohmart (1984) found that a mature cottonwood-Russian olive site with little human use had significantly lower total bird density than a similar habitat near downtown Albuquerque. Hink and Ohmart suggested that direct human activity may have influenced avian habitat use in this situation.

Causes of differences in species composition patterns between BNWR and RGNC are unclear, but may be related to the north or south distributional limits of a species; differences in habitat structure, quality, and quantity at each site; variation of migration routes among species; or weather conditions at stopover time. For example, in the middle Rio Grande valley, the BNWR probably represents the northern distributional limits of Pyrrhuloxia and Verdin. No individuals of these two species were detected during intensive surveys at RGNC. The Yellow-billed Cuckoo, a sensitive species because of its population declines in parts of the West (Breeding Bird Survey, see Peterjohn et al. 1995), was captured only at BNWR. The weekend banding program at RGNC operated by Rio Grande Bird Research Inc. since 1979 has not captured any Yellow-billed Cuckoos since 1990. This species generally nests in lowland deciduous woodlands, willow and alder thickets, second-growth woodlands, deserted farmlands, and orchards (Johnsgard 1986). We speculate that habitat conditions are more suitable at BNWR for this large, wary species than at RGNC owing to reduced habitat disturbance and recreation by humans.

Although relative abundance data from studies by Hink and Ohmart, Hoffman, and ourselves are qualitative, somewhat subjective, and associated with variations in time, location, efforts, and techniques, nevertheless, the high similarities in species composition and abundance levels between our study and the other two studies suggest that (1) the different investigators were relatively consistent in assigning species abundance levels, (2) relative abundances of many landbird species along the middle Rio Grande have remained relatively stable based on the general abundance levels we assigned, and (3) observed differences among studies in relative abundances of certain species may indicate temporal changes in some populations from 1981-83 (Hink and Ohmart 1984) and 1987-90 (Hoffman 1990) to 1994 (our study).

Brown-crested Flycatcher, a species that was not recorded during the previous two studies was captured during spring and fall migration at

BNWR. BBS data demonstrate that populations of Brown-crested Flycatcher significantly increased 6.7% per year on average from 1980 to 1994 in the West. Throughout the United States, Wild Turkey populations showed a significant yearly increase of 10.5% from 1980 to 1994 (BBS). The Rio Grande race (*M. g. intermedia*) of the Wild Turkey was reintroduced to the BNWR in 1974, and its population has since become well-established in the middle Rio Grande Valley (Peggy Mitchusson, BNWR Wildlife Biologist, personal communication).

In contrast, some species showed consistent population declines based on changes in relative abundance and BBS trends. For example, Hink and Ohmart classified Olive-sided Flycatcher as a common species in the middle Rio Grande, but Hoffman classified it as rare, and we classified it as uncommon. Because the population trend for Olive-sided Flycatcher (based on 320 BBS routes distributed nationwide) shows a declining rate of -3.7% per year from 1980 to 1994, the changes in flycatcher relative abundance between study periods may reflect real decreases along the middle Rio Grande.

Discrepancies in relative abundances between studies were noticed for several uncommon and rare species such as Indigo Bunting, Gray Catbird, and Yellow-breasted Chat. Species that were detected during this study but not by Hink and Ohmart or Hoffman were generally identified as rare or accidental species. Disparities in detection rates could result from use of different counting techniques by the three studies. Very rare species are often only detected during mist-netting operations, a technique we used but Hink/Ohmart and Hoffman did not use. This probably explains why we recorded more species in total during one sampling year than did either of the other two studies over multiple-year periods.

Southwestern Willow Flycatcher is state-listed as endangered in New Mexico, Arizona, and California, and was federally listed as Endangered in 1995 (US Fish and Wildlife Service 1995). Southwestern Willow Flycatcher is a riparian obligate species that nests in cottonwood-willow and similar habitats. This subspecies historically bred south of the Santa Ynez river in southern California, east across Arizona, the extreme southeastern corner of Nevada, southern Utah, possibly southwestern Colorado, throughout New Mexico, and into western Texas (Unitt 1987; Browning 1993). The population decline of this subspecies is apparently due to progressive loss of suitable riparian habitats, especially shrub willow and backwater ponds that supply nesting habitat for the birds, and brood parasitism by the Brown-headed Cowbird (Tibbitts et al. 1994; USFWS 1995). In 1987, Hubbard speculated that only about 100 pairs of Southwestern Willow Flycatchers were left in New Mexico, although recent surveys organized by New Mexico Game and Fish Department report twice that number (Sartor Williams III, personal communication). Earlier and current studies and conservation policies for Southwestern Willow Flycatcher focus primarily on its breeding biology. Given that the species is migratory, using riparian habitats while traveling in spring and fall, we suggest that the persistence of this subspecies could also depend on survival success during annual migration.

Conservation of riparian habitat and migratory landbirds

The population status of neotropical and short-distance migratory landbirds in North America has been the subject of considerable interest, as evidence suggests that many of them are declining and that these declines have accelerated in recent years (Droege and Sauer 1989; Robbins et al. 1989; Teborgh 1989; Askins et al. 1990; Finch 1991). Longterm banding data from Rio Grande Nature Center, New Mexico, suggest that some migratory landbird species that use the Rio Grande corridor such as Western Tanager, Solitary Vireo, Western Wood-Pewee, and Brown Creeper have declined during the last ten years (Wang and Finch unpublished). Riparian habitats provide resources for more species of breeding birds than surrounding uplands (Knopf 1988). The most productive cottonwood stands can have as many as 1,000 pairs or more breeding birds per 100 acres (Carothers et al. 1974). Some avian species that inhabit riparian habitats, such as Willow Flycatcher and Bell's Vireo, are specific in their habitat requirements. Consequently, as riparian habitats decrease in area and/or suitability, so may the abundances of these habitat-specific species (Yong and Finch 1995). Loss of riparian habitats in the Southwest could potentially affect 78 (47%) of approximately 166

avian species that breed in riparian habitats of the region (Johnson et al. 1977).

The conservation of migratory species is complicated by the very life history characteristic that permits these birds to exploit seasonal environments, namely migration (Morse 1980; Terborgh 1989; Finch 1991; Moore and Simons 1992). Declines in populations of neotropical and short-distance migratory species have been attributed to events associated with both breeding and overwintering areas. The rapid rate of deforestation in tropical areas, for example, has been implicated in population declines of many forest-dwelling landbird migrants (Lovejoy 1983; Rappole et al. 1983; Robbins et al. 1989a). Other data point to the importance of changes in suitability of breeding habitats (Whitcomb 1977; Hutto 1988). For example, forest-interior migrants are reported to be especially "area sensitive" (Robbins 1980; Robbins et al. 1989b), which explains, in part at least, why fragmentation of forested breeding habitat has been implicated in loss of migratory birds (Lynch and Whigham 1984; Wilcove 1988).

The persistence of migrant populations depends on the bird's ability to find favorable conditions for survival throughout the annual cycle (Morse 1980). Consequently, problems associated with the *en route* ecology of migrants must factor into any analysis of population dynamics (Moore and Simons 1992). When migrants stopover, they must adjust their foraging behavior to unfamiliar habitats, resolve conflicting demands of predator avoidance and food acquisition, compete with other migrants and resident birds for limiting resources, respond to unpredictable and sometimes unfavorable weather, and correct for orientation errors (Moore and Simons 1992). These problems are magnified when migrants cross inhospitable environments, such as deserts, and arrive at stopover sites with depleted energy stores. As stopover habitat is transformed, degraded or disappears, the likelihood of solving such problems decreases, the cost of migration increases, and successful migration may therefore be jeopardized (Moore et al. 1993; Moore et al. 1995). Consequently, riparian corridors may provide suitable habitat at an especially critical time for migrating birds.

Research programs are urgently needed to monitor changes in bird populations and habitats during different seasons (Martin and Finch 1995) along the Rio Grande. Traditionally, most research and management pertaining to landbird conservation have focused on the breeding period. The data presented in this study suggest that the migration period is also important for birds. To account for the habitat needs of migrating birds in management and restoration plans, spring and fall use of riparian corridors by landbird migrants should be evaluated. We recommend that studies be designed to characterize the *en route* habitat use by migrants, including daily and seasonal patterns of avian species richness and abundance among habitats.

To effectively conserve migratory landbirds that travel through the Southwest, natural resource managers require basic information on the importance of riparian corridors as stopover habitat. Unfortunately, the composition and extent of floodplain riparian vegetation along the middle Rio Grande has been altered more than any other vegetation type in New Mexico by human-induced hydrological and ecological changes during the last two centuries (Bullard and Wells 1992; Dick-Peddie 1993). Although the Rio Grande riparian habitat appears continuous, in actuality it is interrupted by human residential areas, presence of exotic woody plants, powerlines, bridges, roads, dams and diversion structures, and protected parks and wildlife refuges interspersed with nonprotected stretches used by livestock and agriculture (Finch et al. 1995). Different types of riparian habitat may vary in suitability for use by migrating landbirds. Moreover, alteration of particular riparian habitats may reduce or enhance suitability as a stopover area. Migrants need suitable habitat during all periods of their annual cycle, and significant loss or deterioration of habitats that alters patterns of use during any time period could lead to population changes. Thus, responses of landbird migrants to variation in riparian habitats, including human-induced alteration caused by urban encroachment, burning, conversion, draining, and flooding, should be assessed.

In conclusion, we encourage new research to address:

- Whether, how, and why migrants select different riparian habitats;
- How habitat variation affects stopover biology, including foraging behavior, stopover length, and rate of fat (re)deposition; and

- How responses to different habitat types or to habitat changes vary among species.

Further understanding of migrant habitat use of exotic woody plants and seral stages of plant communities is needed to determine what habitats resource managers should manipulate or restore to benefit migrants. Research on migrant use of riparian landscapes is needed to estimate suitable quantities and configurations of habitat types, structural classes, and seral stages to meet the differing needs of multiple species. Inducing regeneration of floodplain vegetation by excluding livestock, planting native species, and introducing flooding will help to mitigate deterioration of riparian habitats and maintain migratory bird populations year-round in this riverine system (Farley et al. 1994). Given the rapid changes in habitat structure and composition of the Rio Grande bosque at the local level (Mount et al. 1996), we recommend that research and conservation be implemented simultaneously and quickly.

ACKNOWLEDGMENTS

We thank John Taylor, Phil Norton, Karen Brown, and the staff of Bosque del Apache National Wildlife Refuge and the Rio Grande Nature Center for access, housing, and assistance with our migratory bird studies at these sites. We thank Rio Grande Bird Research, Inc. for providing logistical support for banding at RGNC. Many volunteers helped us, including members of Rio Grande Bird Research, Inc. who operated mist-nets. John Hubbard, Chuck Hundertmark, and Chuck Hunter provided valuable information for establishing banding sites. Gustav R. Bodner and Heather Bingham assisted with data entry and analysis. Field work was assisted by Gustav R. Bodner, David Hawksworth, Matthew Mahrt, Jennifer Sevigney, Michael Sevigney, Greg Trujillo, Lee Vento, Robert Wolbert, and Richard Young. Finally, we thank Frank Moore for facilitating arrangements for a cooperative agreement between University of Southern Mississippi and Rocky Mountain Experiment Station to support a Visiting Scientist postdoctoral position in Albuquerque, NM for Wang Yong.

LITERATURE CITED

Aldrich, J.W. 1951. A review of the races of the Traill's Flycatcher. Wilson Bull. 63: 192-197.

Almand, J.; Krohn, W. 1979. The position of the Bureau of Land Management on the protection and management of riparian ecosystems. Pp 259-361. In: R. Johnson and F. McCormick, editors. Strategies for protection and management of floodplain wetlands and other riparian ecosystems. USDA Forest Service, Washington, D.C. General Technical Report WO-12.

American Ornithologists' Union. 1983. Check-list of North American Birds, 6th ed. American Ornithologists' Union, Washington, DC.

Askins, R.A.; Lynch, J.F.; Greenberg, R. 1990. Population declines in migratory birds. Current Ornithology. 7: 1-57.

Browning, M. R. 1993. Comments on the taxonomy of *Empidonax traillii* (willow flycatcher). Western Birds 24: 241-257.

Bullard, T.F.; Wells, S.G. 1992. Hydrology of the middle Rio Grande from Velarde to Elephant Butte reservoir, New Mexico. U.S. Department of Interior, Fish and Wildlife Service Research Publication 179.

Carothers, S.W.; Johnson, R.R.; Aitchison, S.W. 1974. Population structure and social organization of Southwest riparian birds. American Zoology. 14: 97-108.

Dick-Peddie, W.A. 1993. New Mexico vegetation: past, present and future. University of New Mexico Press, Albuquerque, NM. 244 p.

Droege, S.; Sauer, J.R. 1989. North American Breeding Bird Survey annual Summary 1988. Biological Report. 89(13): 1-16. U.S. Fish Wildlife Service, Washington, DC.

Farley, G.H.; Ellis, L.M.; Stuart, J.N.; Scott Jr, N.J. 1994. Avian diversity in different-aged stands of riparian forest along the middle Rio Grande, New Mexico. Conservation Biology. 8: 1098-1108.

Finch, D.M. 1991. Population ecology, habitat requirements, and conservation of Neotropical migratory birds. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. General Technical Report RM-205.

Finch, D.M.; Wolters, G.L.; Yong, W.; Mund, M.J. 1995. Plants, arthropods, and birds of the Rio Grande. Pp. 133-164. In: D.M. Finch and J.A.

Tainter, editors. Ecology and Sustainability of the Middle Rio Grande Basin. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado. General Technical Report RM-268.

Hehnke, M.; Stone, C.P. 1979. Value of riparian vegetation to avian populations along the Sacramento River system. Pp. 228-235. In: R. Johnson and J.F. McCormick, editors. Strategies for protection and management of floodplain wetlands and other riparian ecosystems. USDA Forest Service, General Technical Report WO-12.

Helms, C.W.; Drury, W.H. 1960. Winter and migratory weight and fat: field studies on some North American buntings. Bird-Banding 31: 1-40.

Hink, V.C.; Ohmart, R.D. 1984. Middle Rio Grande Biological Survey. Final Report. Army Corps of Engineers Contract No. DACW47-81-C-0015. Tempe, AZ: Center for Environmental Studies, Arizona State University. 160 p.

Hoffman, S.W. 1990. Bosque biological monitoring program: Bird population surveys in Rio Grande Valley State Park (1987-1990). Report submitted to City of Albuquerque, Open Space Division.

Hubbard, J.P. 1978. Revised check-list of the birds of New Mexico. New Mexico Ornithology Society Publication No. 6. 120 p.

Hubbard, J.P. 1987. The status of the willow flycatcher in New Mexico. Endangered Species Program, New Mexico Department of Game and Fish, Santa Fe, New Mexico. 29 p.

Hutto, R.L. 1988. Is tropical deforestation responsible for the reported declines in neotropical migrant populations? American Birds. 42: 375-379.

Johnsgard, P.A. 1986. Birds of the Rocky Mountains. Colorado Associated University Press, Boulder, CO. 504 p.

Johnson, R.R,; Haight, L.T.; Simpson, J.M. 1977. Endangered species vs. endangered habitats: a concept. Pp 68-79. In: R. Johnson and D. Jones, editors. Importance preservation and management of riparian habitat: a symposium. USDA Forest Service, Rocky Mountain Experiment Station, Fort Collins, CO. General Technical Report RM-43.

Knopf, F.L. 1988. Conservation of riparian ecosystems in the United States. Wilson Bulletin. 100: 272-284.

Ligon, J.S. 1961. New Mexico birds and where to find them. The University of New Mexico Press, Albuquerque, NM. 360 p.

Lincoln, F.C. 1979. Migration of birds. Circular 16. Fish and Wildlife Service, United States Department of the Interior. 119 p.

Lovejoy, T. 1983. Tropical deforestation and North American migrant birds. Bird Conservation. 1: 126-128.

Lynch, J.F.; Whigham, D.F. 1984. Effects of forest fragmentation on breeding bird communities in Maryland, USA. Biological Conservation. 28: 287-324.

Martin, T.E.; Finch, D.M. 1995. Introduction: Importance of knowledge and its application in neotropical migratory birds. Pp. xiii-xvi. In: Martin, T. E. and D. M. Finch, editors. Ecology and Management of Neotropical Migratory Birds. A Synthesis and Review of Critical Issues. Oxford University Press, New York, NY. 489 p.

Moore, F.R.; Simons, T.R. 1992. Habitat suitability and stopover ecology of Neotropical landbird migrants. Pp. 345-355. In: J.M. Hagan, III and D.W. Johnston, editors. Ecology and conservation of Neotropical migrant landbirds. Smithsonian Institution Press, Washington, DC.

Moore, F.R.; Gauthreaux Jr., S.A.; Kerlinger, P.; Simons, T.R. 1993. Stopover Habitat: management implications and guidelines. Pp. 58-69. In: D.M. Finch and P.W. Stangel, editors. Status and management of Neotropical migratory birds. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. General Technical Report RM-229.

Moore, F.R.; Gauthreaux Jr., S.A.; Kerlinger, P.; Simons, T.R. 1995. Habitat requirements during migration: Important link in conservation. Pp. 121-144. In: T.E. Martin and D.M. Finch, editors. Ecology and Management of Neotropical Migratory Birds. A Synthesis and Review of Critical Issues. Oxford University Press, New York, NY. 489 p.

Morse, D.H. 1980. Population limitations: breeding or wintering grounds? Pp 437-453. In: A. Keast and E. Morton, editors. Migrant birds in the neotropics. Smithsonian Inst. Press, Washington, DC.

Mount, J.; Krausmann, W.; Finch, D.M. 1996. Riparian habitat change along the Isleta-Belen reach of the Rio Grande. In: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report, Fort Collins, CO, this issue.

Noss, R.F.; LaRoe III, E.T.; Scott, J.M. 1995. Endangered ecosystems of the United States: a preliminary assessment of loss and degradation. National Biological Service, Biological Report 28. 58 p.

Ohmart, R.D. 1994. The effects of human-induced changes on the avifauna of western riparian habitats. Studies in Avian Biology. 15: 273-285.

Partners in Flight. 1992. Preliminary lists of migrants for Partners in Flight Neotropical migratory bird conservation program. Partners in Flight Newsletter, Vol. 2, No. 1: 30.

Peterjohn, B. G.; Sauer, J. R.; Robbins, C. S. 1995. Population trends from the North American Breeding Bird Survey. Pp. 3-39. In: Martin, T. E. and D. M. Finch, editors. Ecology and Management of Neotropical Migratory Birds. A Synthesis and Review of Critical Issues. Oxford University Press, New York, NY. 489 p.

Pyle, P.; Howell, S.N.G.; Yunick, R.P.; DeSante, D.F. 1987. Identification guide to North American Passerines. Slate Creek Press, Bolinas, California.

Rappole, J.H.; Morton, E.S.; Lovejoy, T.E.; Ruos, J.L. 1983. Nearctic avian migrants in the neotropics. USDI Fish and Wildlife Service. U.S. Government Printing Office.

Robbins, C.S. 1980. Effect of forest fragmentation on breeding bird populations in the Pidmont of the mid-Atlantic region. Atlantic Naturalist. 33: 31-36.

Robbins, C.S.; Sauer, J.R.; Greenberg, R.S.; Droege, D. 1989a. Population declines in North American birds that migrate to the neotropics. Proc. Natl. Acad. Sci., USA. 86: 7658-7662.

Robbins, C.S.; Dawson, D.K.; Dowell, B.A. 1989b. Habitat area requirements of breeding forest birds of the middle Atlantic states. Wildlife Monograph 103: 1-34.

Rosenberg, K.V.; Ohmart, R.D.; Hunter, W.C.; Anderson, B.W. 1991. Birds of the Lower Colorado River Valley. The University of Arizona Press, Tucson. 416 p.

Stevens, L.E.; Brown, B.T.; Simpson, J.M.; Johnson; R.R. 1977. The importance of riparian habitat to migrating birds. Pp. 156-164. In: R. Johnson and D. A. Jones, Jr. editors. Importance, preservation and management of riparian habitat: a symposium. USDA Forest Service General Technical Report RM-43.

Tellman, B.; Cortner, H.; Wallace, M.; DeBano, L.; Hamre, R. 1993. Riparian management: common threads and shared interests. A western regional conference on river management strategies. USDA, Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. General Technical Report RM-226. 419 p.

Terborgh, J.W. 1989. Where have all the birds gone? Princeton Univ. Press, Princeton, New Jersey.

Tibbitts, T.J.; Sogge, M.K.; Sferra, S.J. 1994. A survey protocol for the Southwestern Willow Flycatcher (*Empidonax traillii extimus*). National Park Service, Flagstaff, Arizona. Technical Report NPS/NAUCPRS/NRTR-94/04. 24 p.

Unitt, P. 1987. *Empidonax traillii extimus*: an endangered subspecies. Western Birds 18: 137-162.

U.S. Fish and Wildlife Service and Canadian Wildlife Service. 1984. North American Bird Banding Techniques. Canada Wildlife Service, Ottawa, Ontario.

U.S. Fish and Wildlife Service. 1995. Final rule determining endangered status for the Southwestern Willow Flycatcher. Federal Register 60(38): 10694-10715. February 27, 1995.

Wauer, R.H. 1977. Significance of Rio Grande riparian systems upon the avifauna. Pp. 165-174. In: R. Johnson and D. Jones, editors. Importance preservation and management of riparian habitat: a symposium. USDA Forest Service, Rocky Mountain Experiment Station, Fort Collins, CO. General Technical Report RM-43.

Whitcomb, R.F. 1977. Island biogeography and "habitat islands" of Eastern forest. American Birds. 31: 3-5.

Wilcove, D.S. 1988. Changes in the avifauna of the Great Smoky Mountains: 1947-1983. Wilson Bulletin. 100: 256-271.

Yong, W.; Finch, D.M. 1995. Age ratio and population trends: A model for testing the causes of population declines of migratory landbirds. Pp 47. In: Abstracts, Joint Meeting of Cooper Ornithological Society and CIPAMEX, April 4-9, 1995, Universidad Autonoma de Baja California Sur, La Paz, Baja California, Mexico.

The potential for implementing partial restoration of the Middle Rio Grande ecosystem

Clifford S. Crawford[1], Lisa M. Ellis[1], Manuel C. Molles, Jr.[1], and H. Maurice Valett[1]

Abstract.—The Rio Grande currently inundates only a small portion of its riparian forests during late spring runoff. Such flood events were once responsible for the germination of cottonwoods and willows along the river, for a mosaic of wetlands mixed with different aged stands of forest, and for enhancement of decomposition and nutrient cycling. River regulation in this century has decoupled the linkage between the floodplain and the river and has led to senescence without replacement of the once dominant native cottonwoods in the Middle Rio Grande (MRG) valley. We propose that partial restoration can be accomplished by re-establishing a regime of seasonal wetting of riparian soils at select sites, most likely in the MRG's southern reach. Our research at Bosque del Apache National Wildlife Refuge suggests that this practice would 1) accelerate decomposition and nutrient cycling within existing stands and 2) promote cottonwood-willow germination on banks and other cleared areas. It could also expedite the creation of wetlands. We outline methods of implementing partial restoration, and emphasize the importance of continuous monitoring by citizen volunteers. With careful planning and implementation, our suggested approaches could be used for other restoration projects in the Rio Grande Basin.

INTRODUCTION: THE NEED FOR RESTORATION

From the time of its origin as a complete river system until regulation constrained its flows in this century, the Rio Grande has inundated its riparian forests, or "bosques," during late spring runoff. Such overbank flooding allowed cottonwood and willow germination along the river, supported a mosaic of wetlands mixed with forest patches of different ages, and enhanced decomposition and nutrient cycling within the forest. Now, due to extensive water management, such flood events are rare and occur only in limited areas where accumulated sediments raise the river bed high enough to allow overbank flow into the riparian zone.

The floodplain has changed greatly in the absence of annual flooding. The once-meandering river lies straightened between levees, and germination of cottonwood seeds on flood-scoured banks has all but stopped. The old mosaic of wetlands and different-aged stands of cottonwoods and willows has been replaced by a nearly wetland-free floodplain, with discontinuous stands of declining cottonwoods which face severe competition from introduced woody species. Further, the cycle of decomposition and nutrient release that once sustained the riverside forests has lost its historic vigor.

The Middle Rio Grande (MRG) runs between Cochiti Dam and Elephant Butte Reservoir and has had a long history of use. Its water has been diverted for irrigation since the days of the early pueblos. Allocation of the diverted water became a major concern to floodplain inhabitants, and eventually resulted in a complex arrangement of water rights (Shupe and Folk-Williams 1988,

[1] *Department of Biology, University of New Mexico, Albuquerque, NM 87131-1091.*

Bokum et al. 1992) that may potentially restict future flood-related restoration in most reaches. Interstate compacts in the early 1900s assured regional water delivery facilitated by channel widening and staightening (Bullard and Wells 1992). In the present century, flood control and drainage have profoundly altered the hydrologic character of both the river and its valley. The flow of impounded water between Cochiti and Elephant Butte is kept lower than most overbank flooding requires. Drainage produced the valley's dramatic loss of wetlands in the 1930s (Van Cleave 1935).

Urban development has played an important role in changes undergone by the MRG ecosystem. Many of the cottonwood stands so admired by Albuquerque residents were "planted" in 1941 by the last great flood before the construction of Cochiti Dam. Now, in the absence of flooding, leaves and woody debris accumulate and decompose slowly on the forest floor where they contribute to a growing fuel load (Molles et al. in press). Bosque fires are on the increase, and humans appear to be causing most of them (M. Stuever, unpublished data).

As the cottonwoods age without effective replacement in kind, expanding stands of Russian olive, salt cedar and other introduced woody and herbaceous plant species are altering the community structure of the MRG riparian zone (Campbell and Dick-Peddie 1964, Hink and Omart 1984, Howe and Knopf 1991, Durkin et al. 1995). The aquatic community, too, is experiencing pronounced change: its mostly extirpated fish fauna is being replaced by introduced species (Platania 1995). To continuous human residents of the valley these changes may seem imperceptibly slow or even nonexistent, but in the context of history they are rapid and reflect the ecological instability, or declining "ecological integrity," of the ecosystem.

Given the magnitude of the valley's transformation, the notion of anything even approaching complete restoration of the MRG ecosystem is unrealistic. However, we contend that parts of the system can be made to function as they did before regulation intervened. Our recent studies of ecosystem-level responses to seasonal inundation, together with background information from a variety of sources, suggest that partial restoration of judiciously selected sites along certain reaches is entirely possible.

In the following pages we first describe the research-based background for this viewpoint, and then consider how and under what circumstances partial restoration could be accomplished. Our rationale for doing this in central New Mexico is hardly unique. A growing interest in the restoration of large floodplain rivers and their riparian zones exists in many parts of the world (e.g. Boon et al. 1992, National Research Council 1992, Hesse et al. 1993; Sparks 1995). While both the concept and the implementation of environmental restoration face social (Vitousek 1994), political (Pastor 1995) and technical (Kondolf 1995) challenges, ignoring the condition of these recently degraded ecosystems only hastens their continuing deterioration. The ultimate losers include the humans who use them, suggesting that it is better to initiate restoration sooner than later.

RESTORATION-RELATED RESEARCH AT BOSQUE DEL APACHE

The ecological basis for partial restoration of the MRG is formally justified in the recommendations of a comprehensive biological management plan (Crawford et al. 1993). Several interacting groups of scientists and resource managers are currently working to develop this foundation. Among them is our team at the University of New Mexico, which is studying the effects of annual flooding on the Middle Rio Grande riparian forest. Our research at Bosque del Apache National Wildlife Refuge began in the late spring of 1991.

For the first two years of the study, we systematically measured a combination of physical (soil, water, meteorological) and biological (population, community, ecosystem) variables in two forest sites isolated from flooding for about 50 years. Site descriptions are given in Ellis et al. (1993, 1994, 1995). Starting in 1993 and using a combination of drain and irrigation water, we began to experimentally flood one of the sites each year between mid-May and mid-June, the period of maximum snowmelt runoff over the past 100 years. The other site, which continues to be monitored in the same way as the flooded forest, is our reference or control site.

In 1994, we established another pair of flood and control sites, this time in a nearby forest strip between the Rio Grande and the levee to its west

(the "river flood" and "river control" sites). Most of this forest is flooded when river flows exceed 4500 cfs; this typically occurs during spring runoff and when heavy summer storms flush tributaries to the north. A groin dike diverts water from one stretch of forest, providing the non-flooded control site. The same variables are monitored at both sets of sites.

Our detailed research results are given in a number of internal reports (Ellis et al. 1993, 1994, 1995) and external peer-reviewed publications (Lieurance et al. 1994, Molles et al. in press). Overall, floods in the isolated forest were characterized by slow-moving water and extremely anaerobic conditions at the soil-litter interface. Month-long flooding during two subsequent years at the isolated site saturated the soil column with water rendered anoxic by respiratory activity on the forest floor and in the saturated rooting zone. Flooding also deposited considerable silt; mobilized nitrogen; promoted high levels of forest floor respiration; and enhanced litter decomposition, decomposer microorganism activity, native cricket activity, root mycorrhizal activity, and growth of large cottonwoods. In contrast, flooding inhibited litterfall, forb growth and ant diversity and activity, and it decreased activity of introduced isopods. (Crickets and isopods consume dead organic material; ants are omnivores and soil movers.) There has been no detectable change in rodent populations.

Meanwhile, the flood at the river site consisted of moving water (averaging approximately 10 cm/sec) that contributed to different conditions on the forest floor. Water at the soil-litter interface remained well oxygenated (never less than 3 ppm dissolved oxygen), reflecting lower litter storage and the influence of moving water. Inundation lasted for two-and-a-half months in the late spring and summer of 1995, with highly oxygenated surface water and deeper anoxic groundwater generally separated. We believe that separation of surface floodwater and groundwater resulted from an impervious layer of silt and clay contributed largely by the Rio Puerco upstream from our study site. Our data show that significantly more silt was deposited in this forest during 1994 and 1995 than was deposited in the experimental forest.

Data on nitrogen fluxes, litter decomposition, mycorrhizal activity, and cottonwood growth are not yet available. However, we do know that forest floor respiration at the river flood site was lower than in the isolated experimental forest, but was much higher than respiration rates in both the control sites that remained unflooded. In addition, litterfall at the river flood site in 1994-95 was significantly greater than in the isolated forest. Crickets appeared to be the most active detritus consumers at the river flood site, while only one arboreal species of ant was common there. The near-absence of herbaceous understory vegetation in the flooded river forest is striking; this is true also of forest-floor leaf litter which, following prolonged flooding, was both washed away and buried by silt. The size-frequency curve of cottonwoods in the river flood site has a significantly greater median value than that of cottonwoods in the isolated sites. Rodents (entirely *Peromyscus leucopus*) are more abundant at the river flood site compared to the river control, suggesting a positive response by mice to flooding.

A MODEL OF THE EFFECTS OF FLOODING AN ISOLATED BOSQUE

Based on our research at Bosque del Apache, we have begun to propose a conceptual model of how an isolated riparian forest can become partially restored in the Middle Rio Grande ecosystem. According to the model, such a forest is initially in a "disconnected phase", reflecting its isolation from overbank inundation. Our research indicates that when an isolated forest is artificially flooded, the externally supplied water triggers what we call a "reorganization phase," immediately characterized by distinct changes in ecological processes and biological populations. Riparian forests regularly flooded by rising water during late spring runoff are, in our view, in a "steady state phase." Although the ecological processes and biological populations of forests in this phase undergo seasonal changes in amplitude, the changes are relatively slight from year to year.

INITIATING AND IMPLEMENTING PARTIAL RESTORATION

The Middle Rio Grande no longer shifts its course within the floodplain, and many of the

plants and animals in its riparian bosques are introduced. Complete restoration to pre-alteration conditions is therefore no longer feasible. However, by applying the knowledge gained from past and current studies, we contend that restoration of function (although not entirely of structure) can be achieved in selected units of the MRG ecosystem.

The goal of such partial restoration should be to establish and maintain a mosaic of riparian forest stands that can be accessed and flooded with relative ease. Ideally, restoration sites should be strung along all reaches of the river. However, political reality dictates otherwise in central New Mexico. Due to land ownership and control along the Rio Grande, and because the degraded northern river bed for the most part precludes overbank flooding, initial restoration efforts should focus on areas south of Belen. Expansive tracts between Bosque del Apache and Elephant Butte appear to have potential, even though now covered by salt cedar. Although total erradication of salt cedar is no longer considered viable, mechanical removal is routinely performed by Bosque del Apache personnel. Moreover, this exotic species can be managed as a minor component of the ecosystem, as recommended in the MRG bosque biological management plan (Crawford et al. 1993), and various studies (e.g., Ellis 1995; Ellis et al. 1995) have shown its biotic diversity to be unexpectedly high.

Partial restoration should emphasize two different types of sites. One is typified by the isolated forest we study at Bosque del Apache. An applied flooding regime at such a site should, according to our initial calculations, lead to a steady state within two to three decades. To achieve that state, water usually will have to be supplied during the runoff season either from the river or from ditches. Groundwater pumping is another alternative, and might be useful if the hard-to-flood northern sites are considered. Whichever method is used, inundation must occur annually in the late spring. Flooding this type of site will enhance the ecological integrity of the established forest, but will not promote recruitment of new cottonwood seedlings since the dense shade of older trees inhibits the growth and survival of newly germinated seedlings (Howe and Knopf 1991).

The other type of site is typified by silt bars and treeless river banks. Such places can be used to create new riparian forests via the germination of flood-planted cottonwood and willow seedlings (e.g. Stromberg et al. 1993). To be usable, the sites should have porous soils and little plant cover, conditions that can be generated by mechanical removal of existing vegetation and/or by previous flood water scouring. John Taylor and his colleagues at Bosque del Apache have had success with a combination of these treatments on the

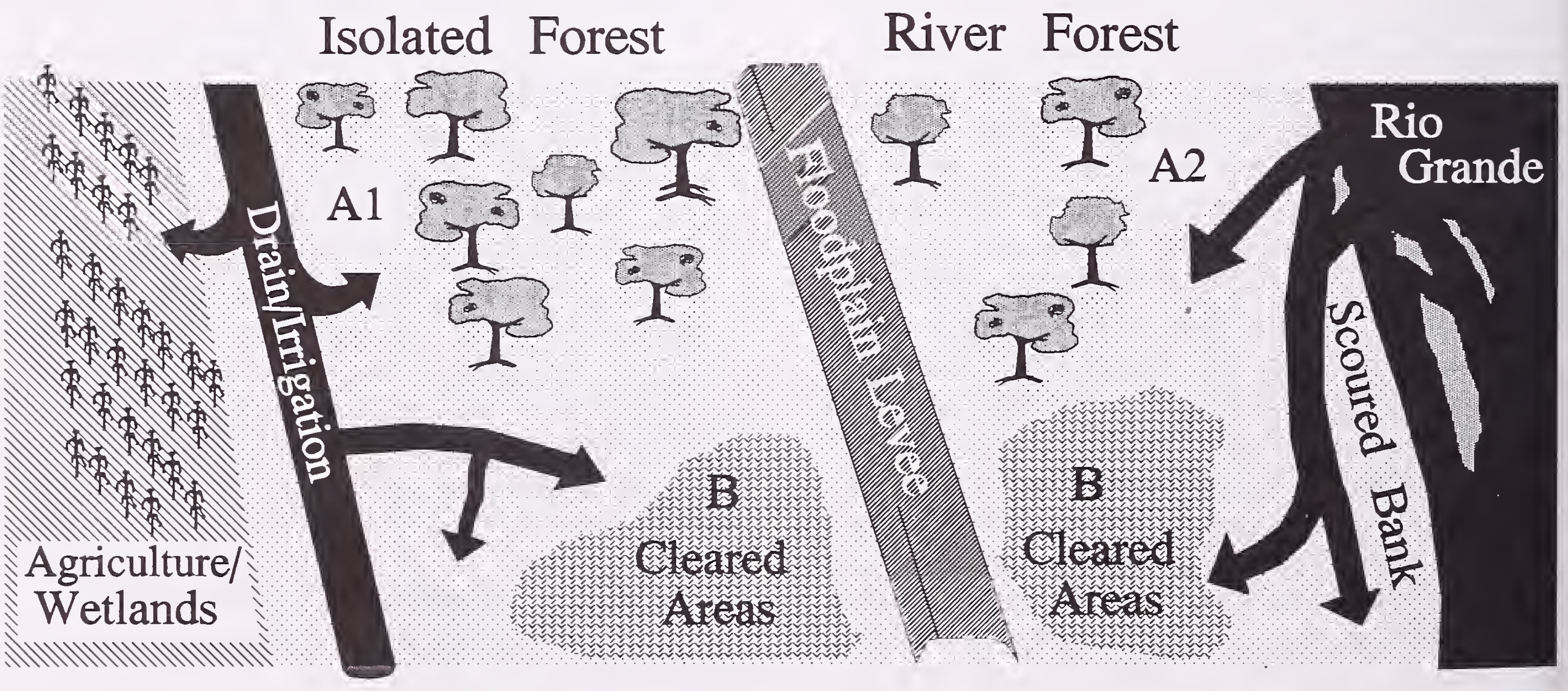


Figure 1. Potential alternative sites suitable for bosque restoration. A1 = forest restoration, A2 = forest maintenance, B = forest creation.

Refuge's west river bank. They have also shown that cleared floodplain distant from the river can produce cottonwood and willow stands as long as the soil is thoroughly wetted when windblown seeds are dispersing (i.e., during peak runoff). Simultaneous germination of tiny salt cedar seeds can be a problem in either case, but if the cottonwood seedlings get a rapid start they compete well (A. Sher, personal communication). Figure 1 shows a schematic indicating the types of sites suitable for partial restoration.

While the first type of site requires repeated flooding, in the second type a single flood can produce highly visible effects. However, although additional late spring floods can add still newer recruits and may nourish existing stands, it should be cautioned that severe flooding can wash out stands of seedlings as well as larger trees.

It should be possible to use both approaches to create a mosaic of different-aged stands. The design of a site where this is planned will obviously require careful study before any treatment is applied. Distances from flowing water, depths to groundwater, permeability of soil, topographic features and soil salinity all should be documented at the initiation of study. Knowing soil salinity is essential since cottonwood germination is not effective in very saline soils (Sheets et al. 1994). For sites where cottonwood can germinate, it will also be necessary to ensure that post-flooding drawdown proceeds at a rate commensurate with the ability of seedlings to send roots downward. Desirable rates of soil drying are discussed in Mahoney and Rood (1991) and Scott et al. (1993).

CONCLUSIONS

While we are confident that partial restoration of the riparian forest can be achieved on selected units of the lower MRG, we realize that a long-term commitment is essential for success. Hence an interagency structure must exist to assure the continuous monitoring of sites undergoing restoration. Monitoring is necessary to know when corrective action is needed and to determine how long-lived organisms such as cottonwoods respond to management actions.

Deciding which variables to monitor will require the combined experience of researchers and resource managers who work in the MRG ecosystem, as well as the expertise of others working in other riverine and riparian systems. Monitoring requires personnel; fortunately, there is a large pool of interested citizens in the valley eager to participate in monitoring. Their involvement would greatly reduce operational costs as well as create a sense of "stewardship" by the citizens of the valley. Funding for the effort should be carefully discussed in advance and solicited from private as well as public sources. A variety of local and regional institutions and industries have a stake in the future of the MRG; convincing them of this is essential. The monitoring operation should be socially and politically defensible as well as cost-effective, well coordinated and well publicized. Educating people about the project should take place at many levels, from young school children through top executives and politicians. The value of ecosystem restoration needs to be understood and accepted by the public as non-threatening and essential to our own well-being.

Successful partial restoration of selected units of the highly visible MRG bosque ecosystem could, if carefully designed and implemented, serve as a standard for other restoration projects in the Rio Grande Basin, and perhaps in other river basins as well. Regularly flooded riparian forests are themselves wetlands (Bayley 1995), but the application of water to the floodplain should also facilitate the re-establishment of marshes and ponds. Momentum is growing for the sustained functioning of once pristine river ecosystems. We think the momentum should include the Middle Rio Grande.

ACKNOWLEDGMENTS

We greatly appreciate the assistance of the many individuals who have helped with our research over the years. Bosque del Apache NWR personnel have been especially helpful in providing study sites and logistical support, as well as contributing ideas. Funding for our research is provided by the U.S. Fish and Wildlife Service and the National Science Foundation.

LITERATURE CITED

Bayley, P.B. 1995. Understanding large river-floodplain ecosystems. BioScience. 45: 153-158.

Bokum, C.; Gabin, V.; Morgan, P. 1992. Living within our means: a water management policy for New Mexico in the 21st century. Santa Fe, NM: New Mexico Environmental Law Center.

Boon, P. J.; Calow, P.; Petts, G. E. (eds). 1992. River Conservation and Management. Chichester, U. K.: John Wiley & Sons.

Bullard, T. F.; Wells, S. G. 1992. Hydrology of the Middle Rio Grande from Velarde of Elephant Butte Reservoir, New Mexico. U.S. Fish and Wildlife Service, Resource Publication 179.

Campbell, C. J.; Dick-Peddie, W. A. 1964. Comparison of phreatophyte communities on the Rio Grande in New Mexico. Ecology. 45: 492-502.

Crawford, C. S.; Culley, A. C.; Leutheuser, R.; Sifuentes, M. S.; White, L. H.; Wilber, J. P. 1993. Middle Rio Grande Ecosystem: Bosque Biological Management Plan. Albuquerque, NM: U.S. Fish and Wildlife Service, District 2.

Durkin, P.; Bradley, M.; Carr, S. E.; Muldavin, E.; Melhop, P. 1995. Riparian/wetland vegetation communities of the Rio Grande: a classification and site evaluation. Final Report. Santa Fe, NM: New Mexico Environment Department, Surface Water Quality Bureau.

Ellis, L. M. 1995. Bird use of saltcedar and cottonwood vegetation in the Middle Rio Grande Valley of New Mexico, U.S.A. Journal of Arid Environments. 30: 339-349.

Ellis, L. M.; Crawford, C. S.; Molles, M. C. Jr. 1993. The effects of annual flooding on the Rio Grande riparian forests: Bosque del Apache National Wildlife Refuge, San Antonio, New Mexico. Progress report submitted to the U.S. Fish and Wildlife Service, Albuquerque.

Ellis, L. M.; Molles, M. C. Jr.; Crawford, C. S. 1994. The effects of annual flooding on Rio Grande riparian forests: Bosque del Apache National Wildlife Refuge, San Antonio, New Mexico. Progress report submitted to the U.S. Fish and Wildlife Service, Albuquerque.

Ellis, L. M.; Molles, M. C. Jr.; Crawford, C. S. 1995. The effects of annual flooding on Rio Grande riparian forests: Bosque del Apache National Wildlife Refuge, San Antonio, New Mexico. Progress report submitted to the U.S. Fish and Wildlife Service, Albuquerque.

Hesse, L. W.; Stalnaker, C.B.; Benson, N. G.; Zuboy, J. R. (eds.) 1993. Restoration planning for the rivers of the Mississippi River ecosystem. Washington, D. C.: U.S. Department of the Interior, National Biological Survey, Biological Report 19.

Hink, V. C.; Ohmart, R. D. 1984. Middle Rio Grande biological survey. Report submitted to U.S. Army Corps of Engineers, Albuquerque, NM.

Howe, W. H.; Knopf, F. L. 1991. On the imminent decline of the Rio Grande cottonwoods in central New Mexico. Southwestern Naturalist. 36: 218-224.

Kondolf, G. M. 1995. Five elements for effective evaluation of stream restoration. Restoration Ecology. 3: 133-136.

Lieurance, F. S.; Valett, H. M.; Crawford, C. S.; Molles, M. C. Jr. 1994. Experimental flooding of a riparian forest: restoration of ecosystem functioning. Pp. 365-374 in Stanford, J. A. and Valett, H. M. (eds). Proceedings of the Second International Conference on Groundwater Ecology. Herndon, VI: American Water Resources Association.

Mahoney, J. M.; Rood, S. B. 1991. A device for studying the influence of declining water table on poplar growth and survival. Tree Physiology. 8: 305-314.

Molles, M. C., Jr.; Crawford, C. S.; Ellis, L. M. Effects of an experimental flood on litter dynamics in the Middle Rio Grande riparian ecosystem. Regulated Rivers: Research and Management. (in press)

National Research Council (US). 1992. Restoration of Aquatic Ecosystems. Washington, D. C.: National Academy Press.

Pastor, J. 1995. Ecosystem management, ecological risk, and public policy. BioScience. 45: 286-288.

Platania, S. P. 1995. Ichthyology survey of the Rio Grande, Santo Domingo and San Felipe Pueblos, New Mexico, July 1994. Report. Albuquerque, NM: U.S. Army Corps of Engineers, Albuquerque District.

Scott, M. L.; Wondzell, M. A.; Auble, G. T. 1993. Hydrograph characteristics relevant to the establishment and growth of western riparian vegetation. Pp. 237-246 in Morel-Seytoux, H. J.

(ed.). Proceedings of the 13th Annual American Geophysical Union Hydrology Days. Atherton, CA: Hydrology Days Publications.

Sheets, K. R.; Taylor, J. T.; Hendrickx, J. M. H. 1994. Rapid salinity mapping by electromagnetic induction for determining riparian restoration potential. Restoration Ecology. 2: 242-246.

Shupe, S. J.; Folk-Williams, J. 1988. The Upper Rio Grande: a guide to decision-making. Santa Fe, NM: Western Network.

Sparks, R. R. 1995. Need for ecosystem management of large rivers and their floodplains. BioScience. 45: 168-182.

Stromberg, J. C.; Richter, B. D.; Patten, D. T.; Wolden, L. G. 1993. Response of a Sonoran riparian forest to a 10-year return flood. Great Basin Naturalist. 5: 118-130.

Van Cleave, M. 1935. Vegetative changes in the Middle Rio Grande Conservancy District. Unpublished Master's Thesis, Department of Biology, University of New Mexico, Albuquerque.

Vitousek, P. M. 1994. Beyond global warming: ecology and global change. Ecology. 75: 1861-1876.

PANEL

Rio Grande restoration: Future directions

Moderated by: Deborah M. Finch[1]

INTRODUCTORY COMMENTS

By Deborah M. Finch

The purpose of this panel was to discuss historical and current changes to the Rio Grande system, focusing on the middle Basin, and to present and review different individual, organizational, and political perspectives on the future of the system. Invitations were made to panelists based on their past and current interests and activities pertaining to restoration of the Rio Grande. Invited panelists included Honorable Senator Pete Dominici or a representative from his staff; Jeff Whitney, U.S. Fish and Wildlife Service Coordinator for the Middle Rio Grande Bosque Initiative; Brian Shields, Director of Amigos Bravos; and Steve Harris, Executive Secretary, Rio Grande Restoration. In addition, Clifford Crawford, Team Leader of the Bosque Biological Management Plan (Crawford, C.S., Cully, A.C., Leutheuser, R., Sifuentes, M.S., White, L.H., and Wilber, J.P., 1993, U.S. Fish and Wildlife Service, Albuquerque, NM), was invited to provide concluding remarks.

I asked participants to be prepared to debate topics related to whether, why, and how the Rio Grande should be restored in light of current ecological, economic, and social realities, including the realities of human population growth, restoration costs, changing water supplies, recreation, regulatory requirements, and ecosystem functioning and health. The following questions were posed to each panel member:

1. What is "restoration" from your individual or organizational perspective, and why is it important or not important?
2. What components should be included in restoration targets?
3. Where is restoration most needed?
4. Should restoration benefit people, or is it justified for other reasons?
5. What are the indirect costs and benefits of maintaining the *status quo* versus restoring the river?

Panel participants were additionally asked to address restoration topics of interest to each of them, including specific projects they or their organizations had undertaken or sponsored. Each panelist was given 10-15 minutes for an oral presentation. After presentations were completed, time was made available for questions and interactions with the audience.

Cheryl Garcia, a Staff Representative for Senator Dominici, was the first speaker, reading a gracious letter by the Senator that reviewed his support of Rio Grande improvement efforts. The Senator's message is presented at the beginning of the Rio Grande section of this proceedings and also here.

LETTER BY SENATOR PETE DOMENICI

By Pete Domenici[2]

Thank you for your invitation to attend today's panel discussion on "Rio Grande Restoration: Future Directions." I apologize for not being able to attend in person, but I hope you will understand that now is a particularly busy time here in Congress.

As we all know, the Rio Grande is synonymous with life in New Mexico. It is this basic fact that

[1] *Project Leader, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, 2205 Columbia SE, Albuquerque, NM 87106.*

[2] *(Presented by Staff Representative, Cheryl Garcia) Pete V. Domenici, United States Senate, Washington, DC 20510-3101.*

makes today's discussion so important. Our State depends on the Rio Grande for so much—for basic water resources, for riparian wildlife habitat, for simple aesthetic beauty—that we simply must make the best decisions about how we use and protect it. Fortunately, recent years have seen important progress being made in crafting policies that will restore and preserve the Rio Grande.

I have tried to help in this regard. For example, I have been involved in the ongoing bosque preservation initiative since 1991, and am happy to say that the Senate has recently approved a $500,000 appropriation to aid in the implementation of recommendations made by the Rio Grande Bosque Conservation Committee. Another $940,000 was also approved by the Senate, at my request, for much-needed rehabilitation of the Bosque del Apache Wildlife Refuge. This money will be used for such projects as a new service and storage facility, replacement of obsolete heavy equipment, and rehabilitation of road and water delivery systems. Finally, the Senate has approved my request for $1 million to continue the U.S. Geological Survey's comprehensive study of the availability of water in the Middle Rio Grande Basin.

Money alone, however, will not solve the problems facing the Rio Grande, and that is why today's conference is so very important. To make lasting progress on Rio Grande restoration, there must also be full and sustained coordination at all levels—federal, state, county, and local. Only in this way, with all of us working together, can we ensure the protection, preservation, and enhancement of this most precious resource.

RESTORATION OF THE MIDDLE RIO GRANDE ECOSYSTEM AND THE BOSQUE BIOLOGICAL MANAGEMENT PLAN

By Jeffery C. Whitney[1]

BACKGROUND/STATUS

For a number of years there has been considerable interest in the Middle Rio Grande and the associated riparian community commonly referred to as "the Bosque". Substantial management activity has occurred along the Rio for many decades. With Senator Pete Domenici's support, a four year process involving the University of New Mexico, the U.S. Army Corp of Engineers, the Bureau of Reclamation, and the U.S. Fish and Wildlife Service, with considerable support and interaction with the community at large, developed the Middle Rio Grande Ecosystem: Bosque Biological Management Plan which was distributed in final form at a public meeting in the fall of 1993.

Within the Bosque Biological Management Plan, there are 21 broad recommendations which are designed to protect and enhance the biological aspects, both aquatic and terrestrial, associated with the Rio Grande riparian ecosystem from Cochiti Reservoir downstream to the headwaters of Elephant Butte Reservoir (190 miles). Implementation of these broad recommendations can and has taken many forms.

The nature of the landscapes, political boundaries, jurisdictions, land ownership patterns and local customs and traditional values all contribute to the past and present condition of the Bosque. The Service is providing leadership and facilitation through the "Bosque Coordinator" and a GIS support person. We, as a community of responsible agencies and individuals, are seeking additional ways to extend and enhance the value of the Middle Rio Grande Ecosystem in our own ways by coordinating with those around us, we hope to create a robust and diverse landscape which includes the social and economic and biological aspects associated with the Bosque.

Toward a coordinated approach to management of the bosque, continued emphasis has been placed on opportunities to implement the Bosque Biological Management Plan (BBMP). In January of 1995 during a Joint Initiatives Meeting (involving the three federal agencies above and numerous other management entities including all water interests) it was decided to hold a meeting with broad representation to initiate a broader and inclusive process designed to further the implementation of the BBMP. At the March meeting it was decided by the group that a retreat would be appropriate to begin to address the questions of:

- What has been accomplished so far toward implementation of the BBMP?

[1] *Middle Rio Grande Coordinator, U.S. Fish and Wildlife Service, Albuquerque, NM.*

- What else could be done with existing resources and authorities?

On May 5th and 6th, 1995, a group of 20 individuals representing federal, state, local agencies and citizens met at the Sevilleta National Wildlife Refuge/ National Science Foundation Long Term Ecological Research Center administered by UNM to explore several aspects of the BBMP to consider the two aspects identified above.

The group felt that it would be beneficial if we developed a product which captured this sense of accomplishment to date. In addition, the product would more clearly identify where we have come from, who we are, what can and should not be done, and where do we go from here.

What we found was that there are many examples of considerable activity which does indeed meet the intent of the Bosque Biological Management Plan. We also agreed that we should reorganize ourselves into a broader and more inclusive loose organization specifically designed to cooperate where possible to further the implementation of the Plan. Thus the Bosque Improvement Group (BIG) was formed.

The Bosque Improvement Group (BIG) is an informal adhoc non-exclusive "think tank". BIG provides a forum for those interested in Bosque Management for cooperation and coordination of ongoing activities involving interagency, intergovernmental, organizational interests, private landowner, and interested citizens within the Middle Rio Grande Reach from Cochiti outflow to the headwaters of Elephant Butte Reservoir.

There is no 'LEAD AGENCY", the Coordinator is only that, a coordinator who assists and facilitates activities which are viewed as beneficial to meeting the intent of the Middle Rio Grande Bosque BBMP. No uninvited intrusion of private property rights is warranted nor intended. For the purposes of general discussion "the Bosque" includes those lands found within existing levees and or immediately associated with the Rio in unleveed floodplain areas of the lower reaches.

TOP PRIORITIES

- Establish a coordinated monitoring program.
- Centralized repository and monitoring coordinator (USFWS funding).
- BIG participation in allocation of the discretionary portion of FWS bosque funds.
- Expand support of local Bosque interest groups (i.e. Socorro's 'Save Our Bosque" group).
- Emphasize continuing evaluation, identification, and monitoring of site potential for revegetation.
- Update vegetation classification and mapping (Hink and Ohmart) to reflect current vegetation structural changes that have occurred since the initial early 1980's H/O Classification.
- Study relocation of levee and low flow conveyance channel (LFCC) from DdANWR downstream. Coordinate planning, scoping, analysis, etc., among agencies.

The recommendations in this Bosque Biological Management Plan define a major shift in long-term management of the Middle Rio Grande bosque ecosystem. The plan emphasizes an integrated management approach, with special emphasis being placed on "communication" and "coordination".

MIDDLE RIO GRANDE ECOSYSTEM: BOSQUE BIOLOGICAL MANAGEMENT PLAN

RECOMMENDATIONS

The Executive Summary of the Bosque Biological Management Plan provides us the impetus to initiate this effort in the following direct quote, "The Bosque Biological Management Plan was created to mitigate that stress in the Middle Rio Grande Valley from Cochiti Dam to San Marcial and to send a message to resource managers and decision makers that a new approach is needed. The plan's purpose is to determine conditions and to recommend action that will sustain and enhance the biological quality and ecosystem integrity of the Middle Rio Grande bosque, together with the river and floodplain that it integrates."

HYDROLOGY

1. Coordinate Rio Grande water management activities to support and improve the

Bosque's riverine and terrestrial habitats, with special emphasis placed on mimicking typical natural hydrographs.

2. Implement measures to allow fluvial processes to occur within the river channel and the adjacent bosque to the extent possible.

3. Reintroduce the dynamics of surface-water/ground-water exchange, manage ground-water withdrawal, and restrict contamination.

II. AQUATIC RESOURCES

4. Protect, extend, and enhance the structure of the aquatic habitat to the benefit of native communities.

5. Protect and enhance surface-water quality.

6. Integrate management of nonnative and native fish species in all aquatic environments in the Middle Rio Grande riparian ecosystem including wetlands, canals, and drains.

III. TERRESTRIAL RESOURCES

7. Protect the geographic extent of the Rio Grande bosque and avoid fragmentation of the riparian ecosystem and component habitats.

8. Protect, extend, and enhance riparian vegetation in noncontiguous areas in the floodplain.

9. Manage the buffer zone of the contiguous bosque to protect ecosystem processes, enhance wildlife habitat values, and maintain rural and semirural conditions.

10. Manage livestock grazing activities in a manner compatible with biological quality and ecosystem integrity.

11. Manage activities that remove wood in manner compatible with biological quality and ecosystem integrity.

12. Manage recreational activities in the bosque in a manner compatible with biological quality and ecosystem integrity.

13. Prevent unmanaged fires in all reaches of the bosque.

14. Use native plant species and local genetic stock in vegetation establishment and management efforts throughout the Middle Rio Grande riparian zone.

15. Protect, enhance, and extend (create) wetlands throughout the Middle Rio Grande riparian zone.

16. Sustain and enhance existing cottonwood communities, and create new native cottonwood communities wherever possible throughout the Middle Rio Grande riparian zone.

17. Contain the expansion of existing large stands of nonnative vegetation in the Middle Rio Grande riparian zone. At the same time, study the ecology of these stands and develop creative ways of maximizing their biological values.

IV. MONITORING AND RESEARCH

18. Develop a coordinated program to monitor biological quality (with emphasis on diversity and abundance of native species) and ecosystem integrity (with emphasis on restoring the functional connection between the river and riparian zone) of the Middle Rio Grande ecosystem.

19. Develop a coordinated research program to study the ecological processes and biotic communities that characterize the Middle Rio Grande riparian ecosystem.

V. IMPLEMENTING AND REVISING THE BIOLOGICAL MANAGEMENT PLAN

20. Regularly review and update the Middle Rio Grande Ecosystem: Bosque Biological Management Plan.

VI. THE MIDDLE RIO GRANDE — PART OF A LARGER RIPARIAN SYSTEM

21. Integrate resource management activities along the Rio Grande and within the contributing watersheds to protect and enhance biological quality and ecosystem integrity.

JUST ADD WATER!

Steve Harris[1]

Thanks to Debra Finch for the honor of participating in this panel. Thanks also to my colleagues on the podium for the work they've undertaken on behalf of the Rio Grande, Rio Bravo, Rio Tiguex, Rio del Norte, this singular, diverse and complex river.

Jeff Whitney, I know to be committed to the Middle Rio Grande Bosque and to the recovery of the Rio Grande Silvery Minnow and not just because it is his job; I get a strong sense that Jeff is personally committed to accomplishing his difficult mission. Brian Shields, has worked for many years toward meeting the goals and aspirrations of the indigenous people for a river they consider sacred; Brian is also now a citizen member of the habitat recovery team for our silvery friend and I applaud him for this and more.

Cliff Crawford is truly the guiding light of the effort to manage the Bosque as a healthy ecosystem. The planning document, of which he is principal author, is a supremely valuable educational resource, as is Dr. Crawford, himself.

Senator Domenici has earned my praise for expending some of his considerable political capital in arranging the public financing of the Biological Management Plan. I hope the Senator won't stop here because much more remains to be done and it will take a considerable commitment from people of the United States if it is to be done.

I apologize in advance if some of my remarks seem critical of irrigated agriculture and a water allocation system in service to agriculture. Agricultural development in the Rio Grande required securing water rights and often these rights were applied with little regard for neighboring users. When the Europeans settled a place, we used resources as fast as we could, because there was always another valley to exploit, somewhere to the west. That's history and we should be aware of it and the nearsightedness of human vision, but I feel we should be aimed at the future. Today, there are signs that irrigation districts are awakening to the needs of each other, the cities and the environment. So I hope my remarks will be a call to greater commitment from these entities, and more and more of us, to rehabilitating a natural river that is now in unmistakable decline.

Sometimes, in the depths of my study, staring at the 12 inch screen, I catch a little of the hopelessness that is often expressed to me, that "can't do" attitude:

- Too many people are too satisfied with the status quo,
- The river basin is filling with thirsty people, like a bathtub, right before our very eyes,
- We really don't "have the budget" to make meaningful change. At such times I'm reminded of what my grandmother said, what everybody's grandmother probably said: "Of course you can't do it, if you don't try."

One evening, a couple of years ago, I was addressing a meeting of the directors of the Conejos irrigation district in Colorado, when an older farmer asked me, "Now, exactly what is it you're trying to restore?"

My short answer was: "some of the flow in the river."

"What good will that do?" he asked.

"Well for one thing, we could keep the fish alive."

He looked thoughtful for a moment, as his mind drifted off to flies cast over clear pools. Then he said, nodding, "I'll bet we could help you out".

Before my heart could leap from my chest for joy, the engineer in charge of the district interjected, "Now, Kelly, I don't think this board should be speaking too precipitously." I wanted to say, "Yes, yes you should".

Because I had already arrived at the conviction that the way to restore the Rio Grande to health is very, very simple:

Just add water!

- Can't get the cottonwoods of the bosque to regenerate?

Just add water.

- All the little fish species are blinking out?

Just add water.

---

[1] *Executive Secretary, Rio Grande Restoration, Inc., P.O. Box 1612, El Prado, NM 87529.*

- Aquifers being mined out, so that the taps of Santa Fe and Albuquerque and Las Cruces and El Paso and Juarez, and beyond are likely to run very salty (or nothing at all) before the middle of the next century?

Just add water.

But, while the solution is simple, providing that solution is a bit more complex. Like: where are we going to get the water? I'd like to briefly tell you about a project that Rio Grande Restoration has undertaken, which has recently gotten a boost in the form of a an opportunity to purchase a considerable amount of privately owned water.

At the very top of the Rio Grande lies the San Luis Valley Closed Basin. For the past 3 million years or so, this area has collected the annual runoff from a portion of the San Juan Mountains on the West and the Sangre de Cristo Mountains on the East. Some of the water has collected in a complex of aquifers which are considered non-tributary to the Rio Grande. By one estimate, the deepest aquifer contains about 2 billion acre feet of sweet water. The shallowest aquifers evapotranspirate over 100,000 acre feet annually.

For the past 90 years, major irrigation diversions in the vicinity of Del Norte , Colorado have added additional recharge to the shallow aquifers in the form of irrigation return flows from water diverted out of the Rio Grande.

For the past several years, the Rio Grande Water Conservation District has been studying the effects of these return flows on the aquifer, in an effort to conjunctively manage surface and groundwater in the Closed Basin. Ray Wright, a closed basin potato farmer who is a member of the Colorado Water Conservation Board (in addition to his membership on the RGWCD board and the three member Closed Basin Project operating committee) says "The Closed Basin is our reservoir". That is, at late season, when streamflows are inadequate to satisfy irrigation needs, farmers pump groundwater to ensure their production, just as other valleys call on surface water captured in reservoirs.

The history of Colorado's performance in delivering its water obligations to the downstream states under the Rio Grande Compact is well known. Before 1985, Colorado had consistently underdelivered its obligations, ultimately accruing a debt of nearly 1,000,000 acre feet to the downstream users. New Mexico and Texas sued Colorado (in 1966) to force them to make timely deliveries and to whittle down the debt. Colorado stipulated, to obtain a continuance in this suit, that it would strictly adhere to Compact delivery schedules.

At the same time, by way of satisfying their water "debt" they resurrected an old proposal to salvage the 104,000 acre feet of water that evapotranpirates from the shallow aquifers of the Closed Basin. And so, at a cost of $100 million, Congress authorized Bureau of Reclamation to construct the Closed Basin Project. Basically, the project consists of a series of 170 shallow wells, including observation wells and plastic-lined, 30 mile delivery canal, which conveys the water production to the river.

While it was being constructed, a series of wet years enabled Colorado to whittle down their debit and in 1985 received the blessing of a spill at Elephant Butte, which forgave the remaining half a million acre feet that Colorado owed. When Closed Basin Project became fully operational in 1993, one of its purposes, satisfying the debt, became moot.

In 1993, the project produced about 40,000 acre feet of water. Over the past two years, the District has operated the Project well under capacity because Colorado had no delivery obligation, due to consecutive spills at Elephant Butte.

During this time, Rio Grande Restoration has engaged San Luis Valley interests in dialogue aimed at getting the District to consider ways of operating the Project for ecosystem benefits downstream. Principally, we have focused on the reach of the Rio Grande around the Colorado-New Mexico state line, where upstream water use often reduces late season flows to a pathetic trickle, with adverse consequences for the ecosystem, fishing and boating in the National Wild and Scenic River. But, of course, having once delivered water to the New Mexico state line, it is possible that the benefits of streamflow will find their way downstream, as well.

On June 1 of this year, it was announced that a 100,000 acre tract, the Luis Maria Baca Grant #4 had been sold to Mr. Gary Boyce and his Stockman's Water Company, whose intention is to offer for sale some 50,000 acre feet of senior surface water rights associated with the Baca Grant. This offer has shifted our focus somewhat from the public project to the private project, though both are

related sociopolitically and hydrologically. The Baca project seems to offer a window of opportunity for a straightforward acquisition of a considerable amount of water that could be used in the restoration of Silvery Minnow habitat and Middle Rio Grande Bosque Biological Management. The US Fish and Wildlife Service has indicated some interest in this proposal. We are now in the process of widening the discussion of this opportunity to include the NM State Engineer's Office and other water managing entities including the Middle Rio Grande Water Conservency District and the Elephant Butte Irrigation District who may be affected.

If you find the concept of a public purchase of private water rights for the restoration of ecosystems intriguing, I invite you to pick up a copy of the discussion paper we prepared for a recent interagency field trip which we sponsored. These are on the table with the Rio Grande Restoration poster.

There's other recoverable water in the basin, San Juan-Chama water, Albuquerque waste water, Rio Costilla and most presently, the products of water conservation: not just from scaling back domestic consumption in Albuquerque, but from water-thrifty crops and low head sprinklers and more cautious use of flood irrigation. The question is:

Do we have the wisdom and the will to apply some of this water to river dependent lifeforms that do not walk erect or seek to harness nature?

A few more, final words about Rio Grande Restoration (the organization):

I think this panel wants to focus today on specific projects and problems related to restoration, and in order to build our organization's capacity we have been engaged in some of these: cattle and elk exclosures, tamarisk eradication experiments, constructed wetlands. We're working with a public-private group to possibly do some ambitious aquatic habitat restoration on the Red River. We're watching with interest our friends in the Bosque's effort to implement the Biological Management Plan. Getting these projects off the drawing board is important and I want to make the point that all can be aided by enhanced streamflows.

In closing, I want to share with you some of our guiding principles represented by aphorisms that are easy to hold in front of us to remind us of our mission and guide our efforts on behalf of the Rio Grande:

"A river's gift to people is the fruits of irrigation; people's gift to a river is streamflow."

This implies a recognition that the original water rights reside in the creatures that inhabit the stream-a recognition that may someday obtain legal force, as a kind of deeper extension of the Winters Doctrine rights now being asserted for Native American peoples. If our domination of rivers is so complete that the web of life in them threatens to unravel, and this is almost certainly the case with the Rio Grande, then we have gone too far. We should begin to recognize our obligation to honor the source of our wealth. And recognize, too, that if we do not honor the other lifeforms that share our world, we condemn ourselves to what Chief Seattle called a "great loneliness of spirit".

"We're all downstreamers".

A beaver pond at 10,000 feet feels the effect of the sheep that have grazed down the grasses above it. The small acequia users feel the effects of the beaver. Alamosa alfalfa growers feel the effects of Summittville. Isleta Pueblo feels the effects of Albuquerque's sewage effluent. El Paso feels the effects of the Hatch and Mesilla valleys' nutrient-laden return flows. Big Bend feels the effect of maquila wastes. The Lower Valley of Texas and Tamaulipas feels the effect of large scale diversions in the Rio Conchos. If we build a low flow conveyance channel to deal with sediment, fish habitat may diminish.

The point is that we're all connected and that none of us can behave as if we had no responsibilities to the next reach of river down the line. We must recognize that our neighbor's interests matter to us, morally and practically. Unseen critters and "frivolous" recreation deserve consideration in the mix, and this they have not had. There is a big picture out there and we must all begin to look closely at it.

"Recreation is neither good nor bad, but only what you make of it."

Rio Grande Restoration's funding derives primarily from the whitewater boating industry and we are often criticized as being insincere in our call for streamflow protection, because of this. In advocating flows for recreation, we take a somewhat broader view of recreation than water to float rafts

or grow exotic trout. Recreation takes many forms: Some are mere sport, sought after to escape the ultimate problem of our mortality and some are more on the order of "re-creation": a sunset walk along the levee, sitting quietly beneath a cottonwood, listening to the voice of the river, seeing a flight of Sandhill Cranes on a frosty morning-things that add a sense of meaning to our lives. Swimming, fishing, boating, birding, walking, running, meditating, the family picnic-all of these are gifts that the river gives us. We believe that these are worthy of protection and enhancement. From a practical side: there are economic values to our communities from a river walk and a river run. Natural values are part and parcel of "tourism products". The fact that we can ascribe a dollar value to whitewater rafting, for example, helps us make a case for river restoration, when we ask for the money to make restoration happen.

If the lawyers are nervous, we must be doing something right."

We recognize that political and legal considerations are a big part of the process of restoring a river. But we believe that the "command-control" paradigm that is the present basis of government management of public resources misses a fundamental target: the assistance of the general citizenry in achieving environmental goals. Likewise the "win-lose" orientation of environmentalist groups is proving ineffective as a model for environmental protection. We prefer to work collaboratively with folks that could be viewed as adversaries, if for no other reason than to move them out of complacency about things we feel are urgent. We recognize that "it's working for us" is a powerful argument. We seek changes that still work for existing uses while placing a more appropriate emphasis on the diversity of life, the importance of water for recreation and ultimately, the notion that rivers need water, too.

Finally, I know another farmer, general manager of the Rio Grande Water Conservation District, actually, who remarked to me after hearing an environmental lawyer on a float trip talking about reallocating existing water rights, "What is he? Some kind of visionary?" I said, "Yes, Ralph, and so are you, because you're talking about this river's "ecosystem". And so must we all be "some kind of visionaries". Because if we don't visualize a future where we share the river equitably with rafters and minnows and Mexicans, the fish and the trees and the farms and the cities and all of us who live in the valleys of the Rio Grande will suffer a thirst like we've never known before and this time, there will be nowhere else to go.

Questions posed by the moderator:

1. What is restoration from your perspective?

I've probably convinced some of you that I am a hopeless pollyanna, unversed in the current complexities of ownership and the real-life, dogged resistance of water managing agencies to reform. I probably think that we can turn back the clock to "a better time". Not so: but I think we can at least reverse the trend toward degradation, restore a small watershed here and a preserve patches of bosque there. Stabilizing ecosystems which are crashing.

Restoring streamflows is the common solution, but my definition of restoration also includes:

- Preserving patches of wildness or naturalness that currently exist.
- Connecting these patches by repairing the damage caused by removing riparian areas (such as by revegetating riverbanks, restoring resacas)
- Abating sources of pollution: (cleaning up sewage discharge, agricultural inputs/wastes, reclaiming mines like Summittville and Red River).
- Deliberately providing the floods that scour the channels and create habitat for aquatic life to exist and riparian species to continue to regenerate and neotropical birds to migrate and breed. (To some extent all of this is possible. In fact, there are growing numbers of folks in the public sector that recogize the need for restoration measures, who see the opportunities out there and are taking first steps toward their accomplishment.)

Restoration also means respecting the carrying capacity of the basin: I'm convinced that we can sustain the uses we've got. It is the new uses, the future uses that are breathing down our necks, that we can't sustain. In the interests of economic development our civic leaders have encouraged industries like Intel to settle here and share our

water. In the interest of improving their own quality of life, thousands of residents of New York and California and Illinois and Michigan have headed, and are still heading for "wide open spaces" in places like Albuquerque. In the interest of sheer survival, a million Mexican citizens have just arrived, and a million more are on the road o La Frontera. And current immigration policy threatens to do no more than stack up the refugees along the Rio Bravo del Norte.

The only answer I see for this dilemma of dilemmas is for the leaders of each and every community in each and every valley to recognize the finite capacity of our river to sustain us and act today, in small, incremental ways, to reduce our communities' demands on the water.

The Clean Water Act, the Endangered Species Act, the Superfund, if they survive, will be very helpful in meeting this litany of challenges. But, alone, they will not be enough to restore the Rio Grande, without the fundamental recognition that: we cannot go on like this. We, biologists and advocates and policy makers and bureaucrats, must carry this message forward to the citizens and leaders of communities in which we reside.

2. Should the Rio Grande be restored?

To the greatest degree possible, yes. What is possible is limited as much by our lack of knowledge, our stifled imaginations, as by our pocketbook.

3. Is it important to restore the Rio Grande?

It is as compelling a national challenge as PACFISH or Mississippi/ Missouri Cooperative Resource effort or Glen Canyon Reauthorization, all strong federal initiatives dealing with costly restoration programs on major national rivers, hopeful programs which every river conservationist supports. I believe the Rio Grande is worthy of this sort of national commitment, not to mention its international importance. Why is it important? The river has given us so much, how can we willfully destroy it? So much is known today about our impacts on the Rio Grande over the last century and over the last 25 years and about what the trends are right now, that we fail to try to reverse our destructive ways only at our own peril. This may require a heroic effort for relatively modest gains, but I believe that the people of the Rio Grande want to see it happen. They want us to show them how.

4. Can we restore the Rio Grande?

I like Dr. Cliff Crawford's idea of selective or partial restorations to re-establish native riparian communities in select sections where conditions, including land ownership seem favorable. Design floods could be provided during years of high runoff, timed to regenerate aging cottonwood communities.

Restoring aquatic habitat in ma mainstem river is more problematic and costly, but no doubt some mainstream segments could be identified where scouring flows could improve stream channels. And in headwaters streams, we have excellent opportunities to restore chunks of overgrazed, overharvested watersheds and preserve healthy ones.

Crawford also speaks of constructed wetlands that mimic the form and function of remnant resacas or to excavate and water historic resacas.

In line with my "just add water" theme, Dr. Crawford suggests that a design flood might have unexpected or "unmanaged" restorative benefits in areas where intensive management is not possible or not undertaken. Having established ecological beachheads, just managing our water as if the river itself mattered would help. The river could perform a lot of the work of restoration.

Another real positive indicator for the feasibility of restoring this river is the sheer volume of people who would respond to a volunteer effort on a cleanup, or a revegetation project or tamarisk removal. Many people in the basin, perhaps a majority would really like to make a positive contribution and don't know how. The many citizens that might be mobilized could create some of Dr. Crawford's wetlands or set out the native plants that could help rehabilitate the IBWC floodway below Caballo Reservoir.

5. Where is restoration most needed?

Restoration of the Rio Grande should flow from the top of the watershed, Willow Creek, Summittville, Red River, where mine wastes are entering the streams, all the way down to the Laguna Madre where accumulated pollution impacts from the river are destroying a formerly biologically rich, diverse estuary.

To return to earth, the Bosque would have to top my wish list. The Bosque has the prerequisites: surviving diversity, a human induced extinction scenario, the existence of what conservation biolo-

gists call "refugia"- suitable habitat to grow wild critters, a solid body of science, including the elements of a restoration plan and a human constituency of friends (including, significantly, the chairman of the Senate Finance Committee).

Restoration is needed in the high impact zones, as well. Streams like the aforementioned, the Red River and the Santa Fe River can be cleaned up and restored, if not to their pristine, pre-Columbian conditions, then to managed streams of which we need not be ashamed.

Finally, the reaches we have transformed into sacrifice zones deserve some of our attention. Specifically, the dewatered sections in the state line reach, the floodways below Cochiti, the dewatered reach between Ft. Quitman and Presidio/Ojinaga deserve loving care. These are areas where we've disconnected the river and where we should give some regard to ways of reconnecting it. Which opens the question of providing so-called "upper basin water" to the lower basin. There is certain to be a market for it, as the Rio Conchos heads for full appropriation of its waters.

6. What components should be included in restoration targets?

Watershed protection: if upper watersheds can retain water for longer periods of time, there will be more water in the system during dry times. Riparian Zones: here is the home of diversity. We should protect the zones that are relatively intact and revegetate where possible to expand the acreage that is available to support life. Aquatic habitat and streamflow also need, and deserve, our stewardship.

7. Should it benefit only people or is it justified for other reasons?

I remind the conferees of Chief Seattle's incredibly penetrating insight: that all forms of life are connected. He said, "The rivers are our brothers. They quench our thirst; they carry our canoes; they feed our children. So you must give to the rivers the kindness you would give any brother." And: "Man did not weave the web of life, he is merely a strand in it. Whatever he does to the web, he does to himself. " He also said that "to harm the earth is to heap contempt on its creator."

I also think that there is a sound economic reason for restoration in the creation of a sustainable visitor economy.

8. What are the costs and benefits of maintaining the status quo vs. restoring the river?

Maintaining the status quo will see our soils continue to run away downstream, leading to a decline in agriculture. It will see the basin's human population grow to unsupportable levels. It will see a number of species decline into extinction. The benefit is that we will save some energy, save some money that might be spent on restoration.

9. Can we afford the costs of restoration?

I've heard it said that a restoration costs 10 times more than preservation. So, it makes sense to hang on to the wild places we've got. The problem is that the impacts will continue to flow into the pristine places.

Without doubt, the dollar costs for restoration could add up quickly. For instance, I wonder whether scientifically prescribed flood flows might be destructive to structures which people have placed within the floodplain, such as in north valley. The costs of restoration can add up if you're talking about having to restrain flood waters from certain areas.

Many people assumed when Cochiti was closed that we now had the absolute power to prevent downstream flooding, but sooner or later there will be a regionwide storm event of sufficient magnitude to run the Jemez and Galisteo and a bunch of dry arroyos. Or the water managers' crystal balls will break, we'll get a precipitous melt on top of a full reservoir. A structure alone will not save the house built in the floodplain.

When you consider what the river has given to its brothers the humans, is $100,000,000 too much to pay in return? I dare say the public treasury has paid several times $100 million in the effort to harness and control the river. How can we accept the argument that we cannot afford some amount of public money to nurture and restore the river?

We can also prioritize projects very carefully, do projects that benefit the greatest geographical areas (and I submit that public water acquisition to provide streamflow, however expensive, falls into this category) do projects that rely upon volunteers or upon many partners. We could also do something on the BECC/NADBANK model, where communities, state agencies, conservation NGO's could apply for long term, low interest loans for restoration projects. This kind of approach makes

fully as much sense as a lot of the Reclamation project repayment contracts that have been subsidized throughout the West over the last 100 years.

10. What specific projects have you or your organization undertaken to restore the river?

The streamflow protection project I mentioned seeks to apply available sources of water to the ecosystem. It also seeks public support for the "radical" notion that a river needs water, too.

We're also involved in a project that promises to experiment with a river degraded by toxic mine wastes. This is barely even on the drawing boards, will take years, has significant political hurdles and may not work. But we are excited by the prospects and committed to it for the long haul.

We also have a growing corps of volunteers to wield the shovel, so to speak. We are developing the capacity to do restorations by contributing to BLM and Forest Service projects in Taos and Rio Arriba County.

PEOPLE RECLAIMING RIVERS: AMIGOS BRAVOS

Brian Shields[1]

The way to protect and reclaim water quality and the riverine ecosystem in the Rio Grande watershed and in New Mexico as a whole is through the empowerment of the grassroots communities which are dependent on that water. Affected communities need the information, coalition-building, legal support and political voice to hold polluters accountable and to reverse river degradation through reclamation initiatives. For this reason, Amigos Bravos—an eight year old grassroots river and social justice advocacy organization, with close to 600 members—operates as a watch-dog and pro-active force with programs which involve both protection and reclamation initiatives. In addition, Amigos Bravos provides technical assistance to communities, organizations and individuals.

In semi-desert country, rivers define communities. Rivers provide the lifeblood that allows communities to maintain a sustainable and productive existence. The people of northern New Mexico who are now in late middle-age recall drinking directly from the rivers as children—without fear—in an act that was both necessary, and, in the case of Native American communities, of spiritual and ceremonial import. Water from springs, rivers and lakes is revered. The Hispanic acequia is an irrigation system, which taps from rivers, around which the Hispanic culture of northern New Mexico is built. Even now there are older people in these communities who will not use a flush toilet because it is inconceivable to them to degrade water in that way.

In less than fifty years, the 1,885 mile Rio Grande has become a health hazard of major proportions. American Rivers named the Rio Grande the Most Endangered River in North America in 1993. The American Medical Association has labeled the lower reaches "a virtual cesspool and breeding ground for infectious disease." Half of the Rio Grande's original fish fauna have disappeared. The silvery minnow is on the brink of extinction. In areas such as the Rio Grande Bosque, a number of species have already disappeared, including the gray wolf, grizzly bear, longnose gar, shovelnose sturgeon, and phantom and bluntnose shiners. The southwestern willow flycatcher is also on the edge of extinction. Meanwhile, the last and best remaining forest of cottonwoods—which stretches along the Rio Grande from Cochiti to Elephant Butte Dam—is in a state of biological crisis. Although it is still possible to swim with impunity in the north, a young boy died this year when he was infected by the water in the lower reaches.

Water quality degradation is occurring from industrial and government waste, municipal sewage discharges and most importantly, non-point source pollution resulting from ill-conceived land and water management practices. Plutonium placer deposits have been found in Cochiti Lake. Mining has killed numerous tributaries of the Rio Grande, including the Red River outside of Questa. Logging is altering water flows and aquifer recharge rates, while non-sustainable grazing practices have turned water into mud from siltification and desertification. Municipalities and industry have pumped out so much water that wetlands and tributary streams go dry. Flows are being

[1] *Amigos Bravos, P.O. Box 238, Taos, NM 87571 (505) 758-3874. Amigos Bravos is funded solely through private and member donations.*

managed in a way that no longer resemble nature's natural rhythms which are designed to generate biodiversity. In short, the entire ecosystem are being altered away from life.

Without citizen action and advocacy, water quality will continue to degrade. People who are frustrated by economic and spiritual decline that is a direct result of a polluted environment will seek the nearest scapegoat and fall prey to the inconsistencies and false premises of corporately-backed, top-down "movements" such as People for the West. Government agencies, whose responsibility it is to protect the public's resources are, by the nature of the bureaucratic process, moved to act according to where pressure is being applied. Historically, that pressure has been applied by "moneyed" interests, including other government agencies such as the Departments of Energy and Defense, municipal leagues, real estate developers, and industry as a whole. In fact, many of the current government regulations were, and are continuing to be, devised in cooperation with those interests.

The purpose of Amigos Bravos is to return the Rio Grande watershed and New Mexico's rivers to drinkable quality wherever possible, and to contact quality everywhere else; to see that natural flows are maintained and where those flows have been disrupted by human intervention, to see that they are regulated to protect and reclaim the river ecosystem by approximating natural flows, while maintaining environmentally sound, sustainable practices of indigenous cultures. Amigos Bravos holds that protection of the environment and social justice go hand in hand.

HOW MUCH CAN THE BASIN HOLD?

Clifford S. Crawford[1]

My colleagues on this panel have addressed, often with eloquence, reasons why the condition of the Middle Rio Grande ecosystem deserves our utmost attention at this moment in the river's history. Indeed, their words appear to reflect the values of many managers, biologists and private citizens attending this timely symposium. As I contemplate their support for a new and different approach to managing the river and its riparian forest, I marvel that such sentiments were virtually unheard of only a few decades ago.

Our current image of how the middle river should appear and function is conditioned by what we now know of its past. However, it was most greatly changed at a time when people were more concerned with survival than with history. To them, an altered river meant security. To many of us, it means that important natural processes have been pushed to the point of no return. Human values change with time and circumstance, but the working of the natural world is based on unchanging principles, one being that continuous use of a resource depends on the resource's availability. If we understand that, we might well want to ask what the Middle Rio Grande ecosystem will be like, not just ten or twenty years from now, but fifty, one hundred, five hundred(!) years from now.

We focus in this panel on the condition of a waterway that collects water from a basin being filled by people like ourselves. Many of us here today came to the middle valley because of the real and imagined opportunities it held for us, and for the beauty and freedom the open spaces seemed to provide. Others have family and tribal histories that, in the basin and the region, go back for hundreds or even thousands of years. Several papers in this symposium have reminded us that abrupt cultural changes involving the use of the Rio Grande floodplain occurred during the last four hundred years. Some of the changes had painful cultural consequences, others led to new levels of prosperity, and all affected the hydrology of the basin.

Irrigation farming followed the floodplain colonization by Spanish settlers, replacing the earlier floodwater and dryland farming of the river pueblos. Water diverted into acequias may not have affected the pattern of groundwater recharge then — but does so now when combined with other changes in basin hydrology. These transformations occurred mainly in the present century but were significantly influenced by grazing and logging on basin watersheds during the previous century. Erosional deposits raised the river bed, and as a result elevated the water table of the

[1] *Department of Biology, The University of New Mexico, Albuquerque, NM 87131-1091.*

adjacent floodplain. The effect on agriculture and floodplain settlements was twofold: rising water in the soil brought salts to the surface, and heavy runoffs from melting mountain snowpacks produced drastic floods. The obvious solutions were to drain the valley and dam the river. However, these technically admirable accomplishments — achieved in the lifetimes of many of us here — created new concerns. Add downstream sediment accumulation, polluted water, a straightened and channelized river, a rapidly declining urban water table, and an invaded and progressively flood-isolated bosque to the abovementioned conversions, and you have what some would call an environmental crisis of major proportions.

To my mind there are two ways to think about the problem. Both are valid and should be pursued. One is to roll up our sleeves and cope with the problem's many facets. Many in this symposium, myself included, are doing this right now, although in our piecemeal approach we tend to lose sight of the need to pull together toward a common goal. The other way is more passive, but in the long run may be more important. It addresses the issue of the basin's **carrying capacity**. How many people and how much human activity as we know it today can the water and water-related resources of the basin sustain? The question directly addresses the issue of **population growth**, not an easy one for politicians to consider seriously—or publicly. Essentially, there is no good answer because nobody knows. And nobody will continue to know until we get together and talk about it.

Thinking about the environmental problems of the local riparian forest and the river responsible for its existence has forced me to face the implications of overreaching the basin's carrying capacity. We may never totally agree on how many of us the basin can hold on a sustainable basis, but in my opinion we had better confront the issue voluntarily before the distorted hydrological cycle makes confrontation mandatory.

Ecosystem hydrology and ecology

Spatial relationships among lightning, precipitation and vegetative cover in watersheds of the Rio Puerco Basin: An introduction

Deborah Ulinski Potter[1] and Susan M. Gorman[2]

Abstract.—This paper explores the question "is there a relationship between seasonal precipitation amounts and vegetative cover at a specific site near Grants, New Mexico?" Several hypotheses will be investigated. One is that the organizing factor for vegetation response to precipitation is the amount of summer precipitation from convective thunderstorms. The variable winter precipitation (high in El Niño years and low in La Niña years) does not provide a dependable amount of moisture, and plant cover or basal areas are not well correlated with it. Alternatively, winter or annual precipitation amount may be the organizing factor for vegetation response. Otherwise, factors such as land use activities, soil type, geological features, temperature, etc., could be the primary organizers of vegetation pattern within the study site. A Geographic Information System (GIS ARC/INFO) vector data structure will be used to organize, analyze and display the data. Final products will include GIS thematic maps of the study area that display precipitation and vegetation data. The results of statistical and spatial operations such as linear regressions, interpolations and kriging will be presented and discussed in a subsequent publication.

INTRODUCTION

It is often assumed that the earth's atmosphere and climate regimes are major controlling factors in the distribution and amount of vegetation in the biosphere (Neilson 1986). Thus, plant distribution patterns can be correlated with the spatial and temporal patterns of available water (Barbour et al. 1980). The response to specific meteorological events (e.g., individual storms, successive days of extreme heat or drought), however, is species specific due to differences in physiology and life history (Neilson 1986). For example, the shallow roots of blue grama are responsive to light rainfall events in semi-arid regions (Sala and Lauenroth 1982).

Water availability is important to ecosystem function, and can be a limiting factor for vegetation in the semi-arid southwest. It affects rates of photosynthesis, regeneration and mortality (Yeakley et al. 1994) as well as resistance to herbivory (Cates et al. 1983, Louda 1992). Variations in precipitation affect plant communities because primary production, precipitation quantity and soil texture are inter-related. For example high precipitation (> 370 mm) on clayey soils is associated with high primary production rates while low precipitation amounts favor good production rates on coarse and rocky soils due to greater infiltration (Risser 1991). Such differences in moisture and temperature regimes are evident in the major vegetation types of NM.

[1] General Physical Scientist, USDA Forest Service, 517 Gold Avenue SW, Albuquerque, NM 87102.

[2] Statistician, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, 2205 Columbia SE, Albuquerque, NM 87106.

Cloud-to-ground lightning strikes have been correlated with measured precipitation (Battan 1965, Vorpahl et al. 1970, Pipegrass et al. 1982, Gosz et al. 1993, 1995). In NM, most lightning occurs during the summer monsoon season (Gosz et al. 1993, 1995). This regional-scale convective pattern usually begins in early July and continues until the end of September (Stensrud et al. 1995). Precipitation that occurs during the winter in NM is due to frontal storms and is generally not accompanied by lightning strikes.

This paper introduces a project that explores the question "is there a relationship between seasonal precipitation amounts and vegetative cover in watersheds of the Rio Puerco Basin?" A schematic of potential organizing factors for vegetation patterns at a specific site is presented in Table 1. These include seasonal precipitation amounts, long-term annual precipitation amounts, and factors other than precipitation.

Seasonal moisture can affect plant community composition. In a study of two fir species, Pavlik and Barbour (1991) determined that red fir was a superior competitor to white fir following high winter precipitation. Also, low summer precipitation favored white fir while high summer precipitation favored red fir. Neilson (1986) distinguished between establishment of warm season (often C_4) species promoted by dry winters and establishment of cool season species (often C_3) that is promoted by wet winters. Also, C_4 grasses that are already established depend on summer moisture. Thus, *seasonal precipitation* amount may be the organizing factor.

Vegetation response to precipitation may be organized by the amount of *summer precipitation* from convective thunderstorms. If variable winter precipitation (high in El Niño years and low in La Niña years) does not provide a dependable amount of moisture, plant cover or basal areas may not be well correlated with it. A prediction that follows is that areas receiving equivalent amounts of precipitation inferred from lightning strike data during the monsoon season of late June through September have a similar vegetation response (measured as basal area or percent cover within the study site). This response may vary by plant species. For example, warm season grasses and forbs may be more responsive to summer moisture than deep-rooted trees which are dependent on winter precipitation for survival.

Alternatively, *winter precipitation* amount may be organizing vegetation response. A prediction that follows is that there will not be a significant relationship between summer precipitation inferred from lightning strike data and vegetative cover. The correlation between precipitation and vegetation might be detectable using winter precipitation amounts, but that relationship would not hold when based solely on the lightning data. Then portions of the study site that consist of vegetation species that are most dependent on winter moisture could be excluded from the lightning-inferred precipitation analyses. For example, data from the Niwot Ridge Long-Term Ecological Research (LTER) site show that alpine vegetation patterns are largely controlled by snow distribution. The study indicated that some species such as *Poa*

Table 1. Potential organizing factors for vegetation at a specific site.

Precipitation	Not precipitation
Seasonal	land use [Naveh and Lieberman 1984]
[Pavlik and Barbour 1991, Neilson 1986]	geological features
Summer	soil type [Risser 1991]
grasses, forbs [Neilson 1986]	solar activity [Scuderi 1993]
Winter	temperature [Briffa et al. 1990]
trees [Walker et al. 1993]	fire history [Swetnam and Baisan 1995]
Long-term Annual	biotic interactions—
(including oscillations and anomalies)	competition, herbivory, etc. [Silvertown et al. 1994]
[Yeakley et al. 1994]	

artica, a bluegrass, are restricted to areas of deep snow. Patterns controlled by snow distribution included plant species, community composition, and green-biomass indicated by normalized difference vegetation index (NDVI) data (Walker et al. 1993).

Another alternative is that *long-term annual precipitation* determines vegetation pattern on the landscape. In this case, precipitation amounts and vegetation patterns should be similar by ecosystem type (e.g., grassland, piñon-juniper woodland, mixed conifer and fir forests). Different ecosystem types may have annual precipitation amounts that are statistically different, but such a relationship would not be assessed using the lightning data because of its temporally-restricted nature. Yeakley et al. (1994) simulated the response of three forests and one grassland ecosystem to oscillations in long-term annual precipitation regimes. There was a substantial above-ground biomass response by forests while shortgrass prairie exhibited a broad tolerance to annual precipitation oscillations. Biomass of the boreal forest was less responsive than either deciduous hardwood forest or a transitional zone of mixed boreal/hardwood forest.

Finally, *factors other than precipitation* (i.e., land use activities, geological features, soil type, solar activity, temperature, fire history, biotic interactions, etc.) may be the primary organizers of vegetation pattern within the study site. For example, Silvertown et al. (1994) noted that while grassland communities were affected by annual changes in weather, indirect effects of competition were more important. Effects of temperature (Briffa et al. 1990) and solar activity (Scuderi 1993) on tree growth have been analyzed using tree-ring records. If such factors are more important, then precipitation amounts inferred from lightning data will not be closely related to vegetative cover.

Study site description

The study site is Pole Canyon within the Rio Puerco Basin, in the west Rio San Jose watershed near Grants, NM (fig. 1). It is within the Mt. Taylor Ranger District, Cibola National Forest. The site was selected for pragmatic reasons, i.e., extensive resource inventory data are available. It is based on a 140 km^2 area that was established by the Forest Service as a prototype for ecosystem management. Their analysis area was defined by administrative boundaries rather than watershed area. If drawn along watershed boundaries, it includes the combined area of Pole Canyon, Limekiln Canyon and Prop Canyon, but excludes the Zuni Canyon fragment.

Pole Canyon is located on the east side of the Continental Divide (Oso Ridge) in the Zuni Mountains. Elevations range from 1,999 m (6,560 ft) to 2,821 m (9,256 ft) at Mt. Sedgwick. The land ownership is primarily National Forest (134 km^2), but the analysis area contains blocks of state land and small parcels of private land. It is traversed by many roads, including state roads 180, 425, 448 and 49, but some forest roads are scheduled for obliteration. Land use activities within the study site include timber harvest, mining, recreation, hunting, and livestock grazing. It is an important area for wildlife habitat, including Mexican spotted owls. The grassland areas have a dense road system, including unregulated 'two-track' roads. The District expresses concern for erosion rates throughout the analysis area. Mineral rights are held throughout extensive areas within the study site, excluding the far north and western portions.

The study site lies within the Navajo Section of the Colorado Plateau Geomorphic Province (USDA Forest Service 1994a). The main geological feature is San Andres Limestone, while the western edge of the site is Pre-Cambrian rock (granite). Dispersed, larger patches of alluvium and sandstone occur, and there are narrow areas of basalt flow to the southwest corner. Small patches of Lower Chinle Formation occur throughout the area.

A Terrestrial Ecosystem Survey (TES) was completed for this area in 1993, but final results are not published. These data include taxonomic name, mean canopy coverage, canopy height, and percent basal area of current vegetation (USDA Forest Service 1986). Vegetation types range from grassland and shrubs at lower elevation to piñon-juniper woodlands at intermediate elevations, through mixed conifer areas at high elevation. Preliminary results are summarized in an unpublished manuscript (USDA Forest Service 1994a). Some representative soil and potential natural vegetation types for some of the 28 soil map units within the study area are shown in Table 2.

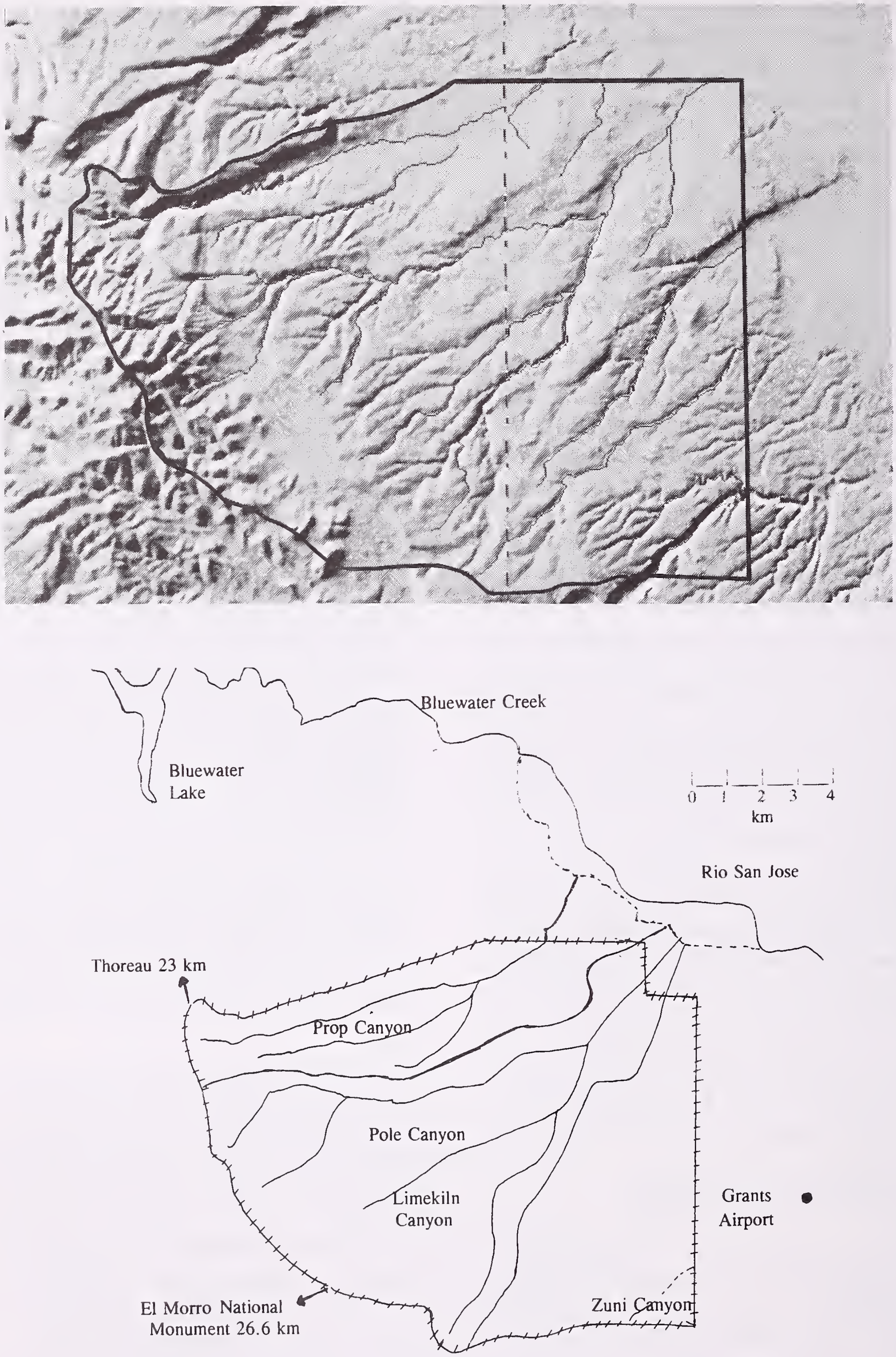


Figure 1. Pole Canyon ecosystem management analysis area (140 km², hatched boundary) located about 3 km west of Grants Municipal Airport, NM. (GIS map prepared by USDA Forest Service, Southwestern Region, Geometronics Group.)

Table 2. Pole Canyon Terrestrial Ecosystem Survey site description of soil and vegetation type by map unit. BA and CC are existing basal area and canopy cover totals for graminoid, forb, tree and shrub classes. Vegetation codes: *Bogr2*, blue grama; *Chna2*, rabbitbrush; *Jude,* alligator juniper; *Jumo*, one-seed juniper; *Pipos*, ponderosa pine; *Pied*, piñon pine; *Psmeg*, Douglas fir; and *Quga*, Gambel oak. Note that map unit numbers were subsequently changed from 30 to 31 and from 510 to 508.

Map unit no.	Type	%BA	%CC
30	Pachic Haplustolls, coarse-loamy, mixed		
	Bogr2 (graminoid); *Chna2* (shrub)	18	46
153	Typic Eutroboralfs, fine, mixed		
	Pipos, Pied, Jude, Jumo (trees); *Quga* (shrub)	18	87
166	Typic Ustochrepts, loamy-skeletal, mixed		
	Pied, Jumo (trees)	11	41
250	Typic Calciustolls, loamy-skeletal, mixed, mesic [Pedon #8]		
	Pied, Jumo (trees)	9	41.2
256	Typic Ustochrepts, loamy-skeletal mixed, calcareous		
	Jumo (trees)	20	49
256	Typic Haplustalfs, fine-loamy, mixed, mesic, calcareous [Pedon #2]		
	Jumo (trees)	17	29
256	Typic Ustrochrepts, loamy-skeletal, mixed, calcareous [Pedon #3]		
	Jumo (trees)	18	31.5
256	Lithic Ustrochrepts, loamy, mixed, calcareous		
	Jumo (trees)	20	45.5
302	Typic Dystrochrepts, loamy-skeletal, mixed		
	Psmeg, Pipos (trees)	12.1	67.6
303	Typic Dystrochrepts, loamy-skeletal, mixed		
	Psmeg, Pipos (trees)	15	73.7
504	Typic Argiborolls, clayey-skeletal, montmorillonitic		
	Pipos, Pied, Jumo (trees)	12	42
504	Typic Eutroboralfs, fine, montmorillonitic		
	Pipos, Pied, Jumo (trees)	20	49.4
510	Typic Argiborolls, clayey-skeletal, montmorillonitic		
	Pipos (trees)	14.2	57
605	Andic Eutrochrepts, loamy-skeletal, mixed		
	Psmeg, Pipos (trees); *Quga* (shrub)	14	58

Grassland areas are primarily located in the northeastern section, and include blue grama, NM needle and thread grass, and western wheatgrass (USDA Forest Service 1994a). A shrubland area of Apache plume occurs in the lower reaches of Pole Canyon. Treeland areas include woodland, conifers, and extremely localized deciduous forest. Conifers are primarily ponderosa pine, some Douglas fir and southwestern white pine. Other dominant species include Gambel oak, mountain mahogany and cliffrose. An aspen stand is found on the northeast aspect of Mt. Sedgwick.

Narrowleaf cottonwoods are primarily within the Pole Canyon drainage (Paul Tidwell, unpublished report). Fire suppression may have affected the vegetation within the area, and conifers are characterized as "unnaturally dense" by the Mt. Taylor District. For example, canopy cover is 100% near Mt. Sedgwick (USDA Forest Service 1994a). A fire history of the area is available from 1975 to present, and it indicates that small lightning fires occur in most years. Fires that originated from human activities were also recorded (Paul Tidwell, unpublished report).

LIGHTNING, PRECIPITATION AND VEGETATIVE COVER

Each of the variables (lightning, precipitation and vegetation) are discussed separately below, followed by a description of the inter-relationships among variables.

Lightning detection

Lightning detection networks locate lightning strokes that are in progress by sensing electromagnetic fields (NOAA 1982, Moran and Morgan 1995). The detection equipment for this study is the Model 141 Advanced Lightning Direction Finder, a product of Lightning Location and Protection, Inc. (LLP) in Tucson (fig. 2). Since 1976 the BLM has operated the lightning detection network for the western United States (Krider et al. 1980). The national network was initiated in 1984 at the State University of New York at Albany, and is currently operated by GeoMet Data Services, Inc., a "sister company" to LLP (GeoMet Data Services, Inc. 1994).

The equipment detects more than 90% of all cloud-to-ground lightning within 370 km, tapering to 70% at the maximum range of 1,110 km (LLP 1987). The accuracy of the detection equipment is

Figure 2. Lightning Location and Protection, Inc. Model 141 Advanced Lightning Direction Finder located at Socorro, NM. Components include antenna assembly (a); electronic module with three circuit boards (b); mast (c); AC power supply (d); and communication and power cables (e). It is part of the national network of wideband magnetic direction finders, an accurate system for lightning detection.

about 2 km (Maier et al. 1984). Accuracy is greatest near the center of the network and less near the periphery. Performance factors include antenna alignment, small random errors due to background noise, site errors due to complex terrain or conducting objects (e.g., power lines) nearby, distance to the detector, and maintenance. The closest instruments to the Pole Canyon site are in Albuquerque and Socorro, NM, and are serviced by the National Interagency Fire Center, USDI Bureau of Land Management, Boise, ID, at least twice per year. These stations are part of a network of gated wideband magnetic direction finders located throughout North America. Five other sites are in NM (Krider 1992).

The detection system consists of the Advanced Lightning Direction Finder, a position analyzer and a system data terminal (Lightning Location and Protection, Inc. 1986). The direction finder determines direction to the lightning strike point using two loop antennas and an electric-field antenna containing top and bottom circuit boards. Thus, it detects an impulse (radio frequency) of the return stroke. The direction finder also contains an electronics module that includes a Central Processor Unit Board, a Pulse Discrimination Logic Board and an Analog Front End Circuit Board. It collects data for strike time, angle, signal strength and number of strokes. The direction finder then transmits the data through the communication cable in binary or ASCII form (by serial link) to a position analyzer. The position analyzer contains a microcomputer system to compute, map and record the location and time of the strike. It combines data from at least two detectors to calculate the location of the lightning flash. Data from the position analyzer is transmitted to a system terminal (remote display processor) that produces color geographic maps.

Data collected from the network operated by the National Interagency Fire Center is transferred by satellite to the Irving Langmuir Laboratory for Atmospheric Research at NM Institute of Mining and Technology in Socorro. From there, data are sent by the INTERNET system to UNM. The raw data are edited using the LLPEDT program and archived in the Sevilleta Long-Term Ecological Research (LTER) data base at UNM. Data were pre-processed prior to being archived. Data processing includes conversions (Greenwich Mean Time to local time; additional fields for Julian day and year), removal of unnecessary diagnostic information, removal of station name for strike detection, and screening for invalid entries. Archived data include eight factors: year of observation, Julian day, time of strike (Mountain Standard Time), latitude, longitude, strength of each strike, number of return strokes per strike, and a reliability code (Gosz et al., 1993, 1995).

Precipitation

NM receives most of its moisture from the Gulf of Mexico, and July and August are the rainiest months (Tuan 1969). According to the Terrestrial Ecosystem Survey, precipitation in the Pole Canyon ecosystem management analysis area ranges from 360 mm yr^{-1} at lowest elevations to 740 mm yr^{-1} in the fir areas near Mt. Sedgwick. Average annual precipitation is 640 mm for mixed conifer areas, 560 mm for ponderosa pine forest, 500 mm for ponderosa pine forests mixed with piñon pine, and 400 mm for piñon-juniper woodlands (USDA Forest Service 1994a). Both summer monsoons and El Niño/Southern Oscillation (ENSO) events affect the precipitation patterns, and are described below.

In NM a significant percent of the total annual precipitation can occur during thunderstorms of the monsoon season. Monsoons are large regional movements of air masses that bring a change in the precipitation pattern. Wet monsoons occur in the summer when there is a seasonal reversal of the winds and a large influx of moisture onto continents. The monsoons that affect NM are the result of a "summer high pressure jump" of 5-10 degrees north latitude off the Pacific coast, and the southward shift of the high pressure system (i.e., the Bermuda High) off of the Atlantic Ocean. The pressure change begins in late June to early July, as east winds bring moisture from the Gulf of Mexico into the southwest.

The large-scale "Mexican monsoon" was described by Douglas et al. (1993). It is centralized over northwestern Mexico, and observed over NM and southern Arizona. Precipitation patterns of the monsoon can be detected by monthly mean rainfall, satellite imagery and rawinsonde data. One index for onset of the monsoon is when dew point temperature at Sky Harbor airport in Phoenix

equals or exceeds 10° C (50° F) for three consecutive days (Gourley, pers. comm.) Douglas et al. (1993) discussed the relative importance of horizontal advection of moist air onto the continent from the east or southeast. Their results emphasize the impact of vertical transport by convection, the lower troposphere as the moisture source, and the contribution of moisture from the eastern tropical Pacific Ocean. Stensrud et al. (1995) suggest that the moisture source for convection is the Gulf of California.

El Niño/Southern Oscillation (ENSO) events are characterized by changes in sea-surface temperatures and atmospheric pressures over the tropical Pacific Ocean. Planetary-scale circulation is affected, and local weather responds in other parts of the world, i.e., at mid-latitudes. This climate link between geographically separate areas is known as a *teleconnection*. The Southern Oscillation is the changing air pressure gradient between the eastern and western tropical Pacific Ocean. The Southern Oscillation Index detects whether climate conditions are "normal", El Niño or La Niña based on the normalized monthly average air pressure difference between Tahiti and Darwin, Australia. During a high index period pressure is high over the eastern Pacific near Tahiti and low over the Western Pacific near Darwin. Conversely, during a low index period pressure rises over the west and falls over the east Pacific Ocean, reducing the pressure difference between Darwin and Tahiti (UCAR 1994).

An El Niño event begins when the air pressure gradient starts to weaken and the southeast trade winds are diminished (Moran and Morgan 1995). During an El Niño event the surface waters of the eastern tropical Pacific Ocean are anomalously warm, upwelling is suppressed off the coast of Ecuador and northern Peru, and the Southern Oscillation Index is low (Dahm and Moore 1994). During a La Niña event, opposite conditions occur, i.e., abnormally low sea-surface temperatures of the eastern tropical Pacific Ocean, exceptionally strong southeast trade winds, and a high Southern Oscillation Index.

Precipitation and runoff regimes in most of NM (i.e., areas other than the eastern plains) have a teleconnection to the El Niño-Southern Oscillation (ENSO) during the fall, winter and spring. High rainfall and spring runoff occurs as a local response to El Niño. As a result precipitation amount during the winter/spring is almost the same as precipitation amount during the summer. The increase in runoff is amplified compared to the precipitation response. Conversely, drought conditions and low spring runoff occur in response to La Niña events (Dahm and Molles 1992, Molles and Dahm 1992). Data for the Gila and Rio Salado watersheds in NM showed that average precipitation was 2.1 to 2.8 times greater in El Niño vs. La Niña years. Also, average spring runoff was 6.0 to 7.4 times greater in El Niño years vs. La Niña years (Dahm and Molles 1992). Increased fire frequency is also associated with La Niña events (Swetnam and Baisan 1995). Although the years 1991-1994 corresponded to an extended El Niño event, precipitation increases are detectable in October through May, rather than during the monsoon season (Dahm and Moore 1994).

Monitoring methods and stations

The most comprehensive precipitation data near Pole Canyon are collected by the National Weather Service. Three sites triangulate the area: Grants airport to the east, Thoreau to the north, and El

Table 3. National Weather Service precipitation monitoring sites near Pole Canyon.

Site Name, ID	Location		Elevation, m
Grants airport, 368204	Cibola Co.	35° 09' 59" X 107° 53' 57"	1987
Thoreau, 883004	McKinley Co.	35° 24' 35" X 108° 13' 50	2177
19 km SE, 883404	McKinley Co.	35° 18' 00" X 108° 08' 50"	2263
El Morro National Monument, 278501	Cibola Co.	35° 02' 17" X 108° 20' 57"	2203

Morro National Monument to the southwest (Table 3). Data for atmospheric moisture are only available at Grants. The Thoreau site was moved during this study period: data collection was terminated at the first location on December 1992, and moved 19 km (12 mi) SE. Data collection at the second Thoreau site began in July 1994. Discrepancies that might occur due to this change can be corrected using the Double Mass Balance Technique (Kohler 1949).

The National Weather Service uses a standard gauge to measure rainfall that accumulates in a cylinder attached to a cone-shaped funnel. A measuring stick calibrated in increments of 0.01 inch is used to record precipitation that accumulates over 24 hours. Methods for surface observations are published by the U.S. Department of Commerce, NOAA (1988). NOAA precipitation and humidity data were purchased from the Western Regional Climate Center, Atmospheric Sciences Center, Desert Research Institute, in Reno, Nevada. Data were obtained on computer disk in American Standard Code for Information Interchange (ASCII) format. Published precipitation data (NOAA 1992-1994) are summarized in Table 4, and indicate that about 40% of the annual precipitation occurs during the months of June through September. At Grants, long-term average precipitation is 253 mm yr^{-1} (Morris et al. 1985). At high elevations near Mt. Sedgwick precipitation amounts would be considerably higher, i.e., 740 mm (USDA Forest Service 1994a). Long-term data for El Morro National Monument show an average precipitation of 307 mm yr^{-1}, compared to 274 mm yr^{-1} at Thoreau (Gabin and Lesperance 1977). These data alone are inadequate to characterize the Pole Canyon study site. Gauges only account for precipitation at a specific site and can not accurately quantify regional precipitation amounts due to the localized nature of summer thunderstorms.

Table 4. Precipitation totals (mm) at selected monitoring sites near Pole Canyon (NOAA 1992-1994).

	1992	1993	1994
Grants			
JUN	11.7	0.0	4.6
JUL	42.7	10.9	21.3
AUG	47.2	107.4	38.1
SEP	31.2	8.9	36.1
Year	344.4	319.3	296.9
El Morro			
JUN	11.2	4.6	17.5
JUL	45.2	2.0	39.6
AUG	76.5	195.1	35.6
SEP	15.0	8.9	46.7
Year	407.7	460.5	397.8
Thoreau			
JUN	5.1	—	—
JUL	56.9	—	29.2
AUG	73.7	—	34.8
SEP	20.6	—	76.5
Year	—	—	—

Vegetative cover

The study site has a wide range in vegetation types along the elevational gradient, and examples are shown in Figure 3. Percent vegetative cover or basal areas could be considered as a coarse measure of primary production or terrestrial ecosystem structure. Factors that can modify vegetative cover include available soil moisture, land use activities (grazing, mining, recreation, etc.), extended drought or flooding, and herbivory. Accelerated soil erosion can cause areas to be less suitable for vegetation growth and reduce productivity. Erosion rates have been a concern throughout the Rio Puerco Basin (USDI Bureau of Reclamation 1994, Watts et al. 1994). The Mt. Taylor District has also expressed concern for existing high densities of dwarf mistletoe, and the potential for increased levels of bark beetles, spruce budworms, and root disease.

The Southwestern Region of the Forest Service has a standardized protocol for the inventory of terrestrial ecosystems (USDA Forest Service 1986; Miller et al. 1993). A completed Terrestrial Ecosystem Survey (TES) was required for each ecosystem management study site, including the Pole Canyon analysis area. Vegetation inventories were completed in 1993 but have not yet been published, and these data will be included in the study. Data for both potential vegetation and observed vegetation are contained in the TES. Potential natural vegetation is "the vegetation that would exist today if humans were removed from the scene and if the plant succession after his removal were telescoped into a single moment. The time

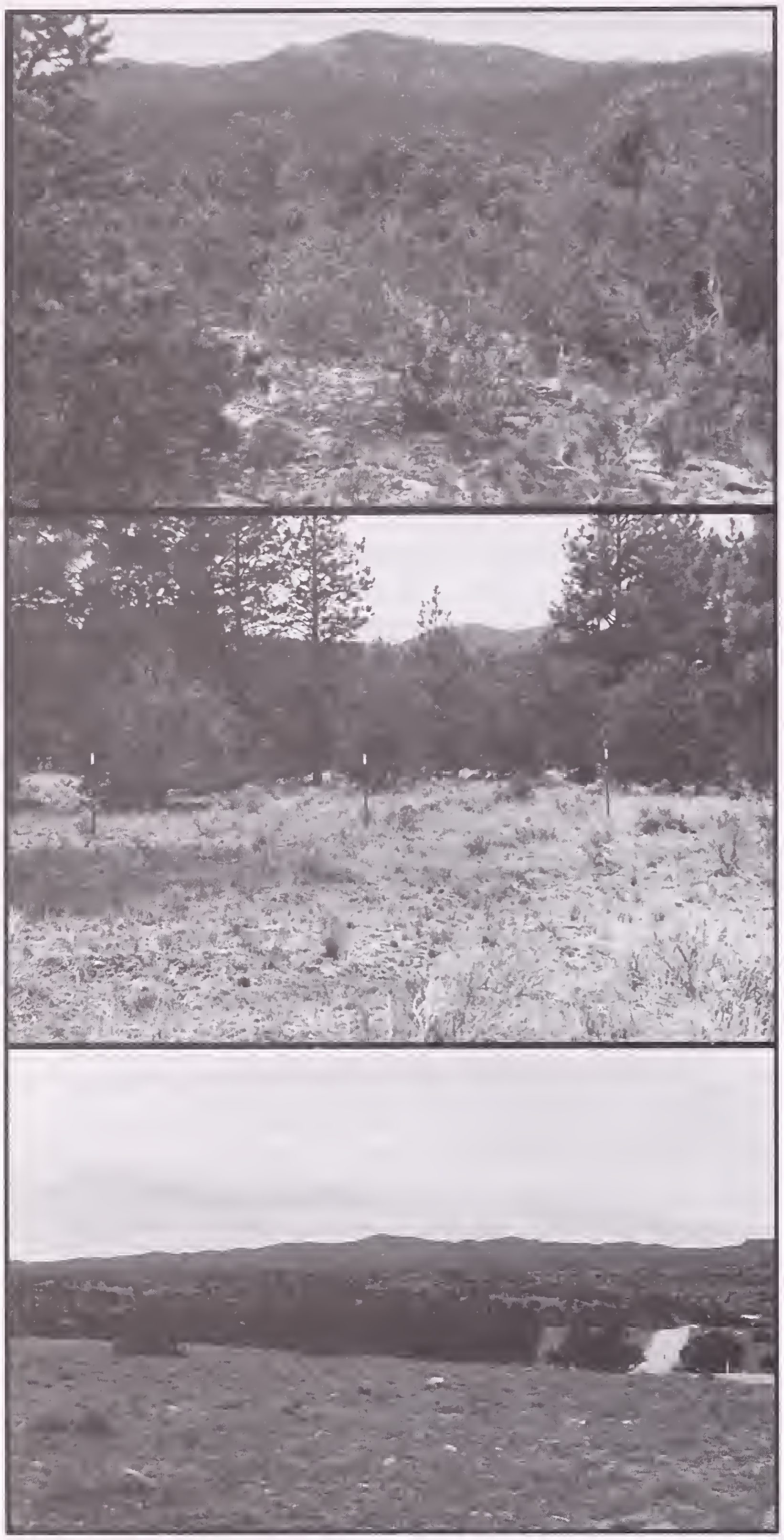


Figure 3. Vegetation gradient within the Pole Canyon study site. Note foreground of piñon-juniper at SR 180 near junction of SR 425 (~ 2,377 m) and background of Mt. Sedgwick fir at 2,821 m (top); ponderosa pine from SR 425 at SE boundary of private land, ~ 2408 m (middle); and foreground of grasses and shrubs near piñon juniper ecotone at ~2,045 m from from above Limekiln Canyon on SR 180 (bottom).

compression eliminates the effects of future climatic fluctuations, while the effects of human's earlier activities are permitted to stand. (National Atlas of the United States, Rev. 1985)" (USDA Forest Service 1993). Potential vegetation is estimated by soil and climate class.

TES reports are based on aerial photographs (1:24,000 scale) and field verification. Map units are initially drawn based on topography, geology and vegetation within stereoscopic views of aerial photographs, and then verified by field surveys. Data for each unit include classifications of climate, soils (taxonomy, depth, rock fragment, soil texture and other), slope, land types, vegetation (taxonomy and canopy coverage) and climax class (climatic, edaphic, topographic, fire or zootic). Vegetation data are recorded both according to species and grouped as trees, shrubs, forbs and grasses. During TES field verification, percent canopy cover and basal area are recorded for at least three site descriptions within each map unit. Sampling sites include 375 m2 circular plots and 25 by 15 m calibration plots for canopy cover measurements. Percent canopy cover is recorded for trees, shrubs, forbs and graminoids. Percent basal area is recorded for combined tree/shrub, graminoid and forb categories and by other classifications such as bare soil. Plant names are abbreviated using standard protocol of the Soil Conservation Service, i.e., the *Plant List of Accepted Nomenclature, Taxonomy and Symbols* (PLANTS) data base.

A separate vegetation survey for existing timber resources was conducted at a finer resolution by the Mt. Taylor Ranger District. Vegetation classes include grassland, shrubland and treeland. Each stand within the treeland areas is rated for effective ground cover as low (< 25%), moderate (26-75%), or high (> 75%). Vertical structure, horizontal structure, dominant species, and habitat type are also recorded for treeland areas. These data are stored in Oracle format in the Rocky Mountain Resource Information System (RMRIS) and could also be used in the analyses.

INTER-RELATIONSHIPS AMONG VARIABLES

The data sets that will be used to determine the organizing factor include the variables precipitation, humidity, lightning strikes and vegetative cover. The first step is to determine the mathematical relationship between precipitation and light-

ning strikes. This will be accomplished by calculating the best-fitting regression equation relating precipitation amount (y^1) to lightning strikes (x_1) and humidity (x_2),

$$\text{i.e., } y^1 = a + b_1x_1 + b_2x_2.$$

Next, precipitation contours for the study site will be drawn based on the multiple regression equation. Finally, the relationship between predicted precipitation amounts (y^1) and vegetative cover within the Pole Canyon study site will be determined by spatial and statistical analyses.

Lightning-precipitation relationship

Some measure of atmospheric moisture is needed to predict precipitation volume from lightning strikes (Gosz et al. 1993, 1995). This adjustment is necessary because if the moisture content of air at the surface is too low then virga (precipitation from the base of a cloud that evaporates completely prior to reaching the ground) will result. Variables that might be used include relative humidity, absolute humidity, specific humidity, and dew point temperature or wet bulb depression.

Humidity is commonly measured indirectly using a psychrometer to obtain a wet bulb and a dry bulb thermometer reading. Actual air temperatures are obtained from the dry-bulb thermometer. The wet bulb provides the temperature due to evaporative cooling. Humidity is determined from the difference between the two readings, called the *wet bulb depression*. A psychrometric table is used to determine the percent relative humidity and dew point temperature using the dry-bulb temperature and the wet-bulb depression. At 100% relative humidity the dew-point, wet-bulb and ambient air temperatures are equal.

Calculations of precipitation that occurs from June through September will underestimate the annual precipitation. For example, on the Sevilleta some lightning strikes occur during the months of May and October, which is outside of the monsoon season (Gosz et al. 1995). This underestimate is due to precipitation from frontal storms. Frontal thunderstorms are typically associated with vigorously-rising air along a cold front's surface that is uplifted to the condensation level. These storms can persist for days (Moran and Morgan 1995). In contrast, convective thunderstorms are associated with rising air due to intense solar heating of the ground and are short-lived. Annual precipitation includes all sources, e.g., both convective and frontal thunderstorms.

Prior studies

This research is based on methods developed by Gosz et al. (1993, 1995). Study sites were the Sevilleta National Wildlife Refuge north of Socorro, NM, and the Pecos River Watershed. They found a significant correlation between precipitation data (collected using a network of tipping-bucket gauges) and lightning strikes within a three km radius of the collection site. One strike resulted in approximately 36,190 m^3 of precipitation within the radius, at an average depth of 1.3 mm. The greatest correlations were produced by multiple regressions between number of lightning strikes, precipitation depth in mm and relative humidity. Analysis of the relationship between lightning and precipitation by month was more accurate than by daily records.

Convective precipitation is often highly random over the landscape. Some analytical problems may arise due to such spatial variability in atmospheric moisture and other variables. The three km radius used by Gosz et al. (1993, 1995) provided the best spatial scale for estimating precipitation according to R^2, the square of the correlation coefficient. Other scales ranging from one to ten km from the gauging site provided less accurate estimates of precipitation. Presumably the three km radius most accurately reflected the scale of thunderstorm cells and the limitations of the lightning detection network.

Precipitation-vegetation relationship

Plant growth as primary production is highly related to both temperature and moisture (Aber and Melillo 1991). Soils provide the major water storage mechanism for terrestrial ecosystems. Thus, both the amount of precipitation and the soil volume and texture determine water availability (Aber and Melillo 1991). Summer precipitation largely affects plant productivity, and can result in rapid growth for grass and forb species (Gosz et al.

1995), but it has high spatial variability. For some vegetation such as warm season grasses, the monsoon season has the greatest effect on vegetation growth since concurrently warm temperatures stimulate growth. In addition, lightning makes nitrogen in the atmosphere available to biota as nitrogen oxides by electrification (Keller 1988). Precipitation that falls outside of the selected months will also affect vegetation growth, and some species depend more heavily on soil moisture from winter precipitation. For example, trees with deep roots may not be able to utilize summer precipitation that does not penetrate deeply into the soil. Thus, winter moisture can be critical for conifer survival.

Extended El Niño events like the 1991-1994 anomaly can greatly increase grass cover in the southwest (Swetnam and Baisan 1995). Drought conditions, including response to La Niña events, produce an increase in fire frequency that is detectable in histories reconstructed from fire-scar data. If fire exclusion has significantly promoted conifer growth in Pole Canyon, then it could affect the direct relationship between precipitation amount (inferred from lightning) and ground cover. Conversely, fire suppression can also promote catastrophic crown fires, which would reduce vegetative cover (Swetnam and Baisan 1995).

Precipitation quantity is one factor that determines the productivity of terrestrial ecosystems, and it is particularly important for semi-arid areas. Other limiting factors include heat (temperature), available sunlight and inorganic nutrients such as nitrogen, phosphorus and trace metals. Too much of a factor, e.g., environmental contaminants, can also be limiting. Thus, any factor near or beyond the limits of tolerance for vegetation growth can be a limiting factor (Odum 1993).

Analysis and products

A Geographic Information System (GIS ARC/INFO) vector data structure will be used to organize, analyze and display the data. It may be necessary to transform all data (i.e,. from ASCII files) to a standard dBASE format for importing into ArcView, etc. Spatial analyses, queries, and data summaries could then be performed in ArcView (ESRI 1994). At least three years of climatological data (e.g., June to September for 1992 - 1994) will be included in the spatial analyses. The statistical and spatial analyses will help determine whether areas receiving equivalent amounts of precipitation during the monsoon season have a similar vegetation response as indicated by vegetation cover. Multiple linear regression (Zar 1974, Kachigan 1991) will be used to develop the correlation between precipitation, humidity and lightning variables at the meteorological sites, and to calculate precipitation depth at other sites based on the lightning data and regression equation. Precipitation isopleths will be generated by spline interpolation. Kriging can be used to select appropriate weights for the interpolation (Venkatram 1988, Star and Estes 1990, Kassim and Kottegoda 1991).

A GIS cross tabulation, i.e., a two-dimensional table of inferred precipitation amount vs. vegetation variables, can be generated to summarize the data. Plots of precipitation amount and number of lightning strikes over time will also be included. The data may be transferred to an external statistical analysis package such as SPSS (SPSS, Inc. 1990) or SAS (SAS Institute, Inc. 1988) for analysis. Precipitation contour maps based on the relationships between lightning and moisture content of the atmosphere will be displayed. The results of statistical and spatial operations such as linear and multiple regressions, interpolations and kriging will be presented and discussed in a subsequent publication. Table 5 contains a list of tasks associated with this project.

ACKNOWLEDGMENTS

This research is funded by Cooperative Agreement No. 28-C4-810 between the UNM Department of Biology and the USDA Forest Service Rocky Mountain Forest and Range Experiment Station (USDA Forest Service 1994b). Steve McWilliams, Cibola National Forest, and Steve Strenger, Southwestern Region of the USDA Forest Service, provided access to the vegetation data. Carrie Christman (Southwestern Region Geometronics Group) served as GIS consultant. Paul Tidwell, Mt. Taylor District, provided background data and a site visit to Pole Canyon. The vegetative data were compiled by the New Mexico TES crew, including V. Andrews, S. Sebring, C. Vaandrager, M. Netharius, and E. Benally. W.L. Smith (*Smitty*) of USDI Bureau of Land Management provided the

Table 5—Lightning research tasks.

Acquire Data for Study Site
• *Lightning — Sevilleta LTER archives (ASCII format)*
• *Precipitation/humidity — Western Regional Climate Center*
• *Vegetation — Forest Service TES data in GIS, rBASE, and hard copy format*
Display Initial Data for Pole Canyon Study Site
• *Potential natural or existing vegetation (trees, shrubs, grass)*
• *GIS maps such as three dimensional elevation map, ownership boundaries, streams*
Check Data Base Structure; Pre-process Data (convert from ASCII to dBASE format)
Lightning Data
• *Clip area containing Pole Canyon site and 5 km square around precipitation sites*
• *Reclip data to new boundaries by watershed, if necessary*
• *Output clipped data to dBASE form*
Lightning-Precipitation Relationship
• *Count number of strikes in (3 km) radius from each precipitation station*
• *Develop linear regression using humidity, precipitation and lightning strikes*
• *Using a (2 km) grid over the study site, count number of strikes in (3 km) radius from each grid point, use regression equation and interpolation to map precipitation amount*
Lightning-Precipitation-Vegetation Relationships
• *Produce cross tabulation of precipitation class vs. percent cover class*
• *Display theme maps if look-up tables can be generated*
Statistics
• *Develop multiple regression to predict precipitation*
• *Interpolate/krig precipitation data*
• *Use external packages like SPSS or SAS for spatial analysis*

manual and site visit to the lightning detector. This research would not be possible without the support of Potter's Dissertation Committee: Manuel C. Molles, Jr., Chair; Louis Scuderi; James R. Gosz; Robert Woodmansee; and Eleonora Trotter. Finally, we want to thank key colleagues who have supported this research effort: Douglas Fox, Jose Salinas, and Deborah Finch.

LITERATURE CITED

Aber, J.D.; Melillo, J.M. 1991. Terrestrial Ecosystems. Saunders College Publishing, Philadelphia. 429 pp.

Barbour, M.G.; J.H. Burk; W.D. Pitts. 1980. Terrestrial Plant Ecology. Benjamin/Cummings Publishing Co., Inc. Menlo Park, CA. 604 pp.

Battan, L.J. 1965. Some factors governing precipitation and lightning from convective clouds. J. Atm. Sci. 22:79-84.

Briffa, K.R.; T.S. Bartholin; D. Eckstein; P.D. Jones; W. Karlen; F.H. Schweingruber and P. Zetterberg. 1990. A 1,400-year tree-ring record of summer temperatures in Fennoscandia.

Cates, R.G.; R.A. Redak; C.B. Henderson. 1983. Patterns in defensive natural product chemistry: douglas fir and western spruce budworm interactions. pp. 5-19. In: P.A. Hedrin, ed. Plant Resistance to Insects. American Chemical Society Symposium Series, Number 208. American Chemical Society, Washington, D.C.

Dahm, C.N.; Molles, M.C., Jr. 1992. Streams in semi-arid regions as sensitive indicators of global climate change. pp. 250-260. In: P. Firth and S. Fishers (eds.) Troubled waters of the greenhouse earth. Springer-Verlag, NY.

Dahm, C.N.; Moore, D.I. 1994. The El Niño/Southern Oscillation Phenomenon and the Sevilleta Long-Term Ecological Research Site. pp. 12-20 In: Greenland, D. (ed.). El Niño and Long-Term Ecological Research (LTER) sites. Publication

No. 8. LTER Network Office, University of Washington, Seattle. 57 pp.
Douglas, M.W.; R.A. Maddox; K. Howard; S. Reyes. 1993. The Mexican monsoon. Journal of Climate 6:1665-1677.
Environmental Systems Research Institute, Inc. 1994. Introducing ArcView. Environmental Systems Research Institute, Inc., Redlands, CA. 98 pp.
Gabin, V.L.; Lesperance, L.E. 1977. New Mexico Climatological Data: Precipitation, Temperature, Evaporation and Wind, Monthly and Annual Means, 1850-1975. W.K. Summers and Associates, Socorro, NM. 436 pp.
GeoMet Data Services, Inc. 1994. National Lightning Detection Network. Tucson, Arizona.
Gosz, J.R.; Moore, D.I.; Grover, H.D.; Rison, W.; Rison, C.; Ward, T.J.; Stevens, K.A.; Bolton, S.M. 1993. Analysis of Relationships Between Lightning, Precipitation, and Runoff. New Mexico Water Resources Research Institute, New Mexico State University, Las Cruces. 42 pp.
Gosz, J.R., Moore, D.I.; Grover, H.D.; Rison, W.; Rison, C. 1995. Lightning estimates of precipitation location and quantity during convective thunderstorms on the Sevilleta Long Term Ecological Research (LTER) site in New Mexico. Ecological Applications 5(4):1141-1150.
Gourley, J.J. 1995. pers. comm. National Severe Storm Laboratory, Norman, Oklahoma.
Kachigan, S.K. 1991. Multivariate Statistical Analysis, 2nd ed. Radius Press, NY. 303 pp.
Kassim, A.H.M; Kottegoda, N.T. 1991. Rainfall network design through comparative kriging methods. Hydrological Sciences 36(3):223-240.
Keller, W.E. 1988. Lightning: a major role in nitrogen fixation. Environment 30(4):21-22.
Kohler, M.A. 1949. On the use of double mass balance analysis for testing the consistency of meteorological records for making required adjustments. Bull. Amer. Met. Soc. 30(5):188-189.
Krider, E.P.; Pifer, A.E.; Uman, M.A. 1980. An automatic locating system for cloud-to-ground lightning. pp. 205-214. In: Lightning Technology. NASA Conference Publication 2128 (FAA-RD-80-30). Proceedings of a technical symposium held at NASA Langley Research Center, Hampton, VA, April 22024, 1980. National Aeronautics and Space Administration, Hampton.
Krider, E.P. 1992. Lightning. pp. 66-68. In: Encyclopedia of Science and Technology. McGraw-Hill, Inc., NY.
Lightning Location and Protection, Inc. 1986. Advanced Lightning Direction Finder Manual. Tucson, AZ.
Louda, S.M. 1992. Plant resistance to insect herbivores: a field test of the environmental stress hypothesis. Ecology 73(1):153-169.
Maier, M.W.; Byerley, L.G.; Binford, R.C.; Hiscox, W.L.; Krider, E.P.; Pifer, A.E.; Uman, M.A. 1984. Gated, wide-band magnetic direction-finders for locating cloud-to-ground lightning. pp. 305-310. In: VII International Conference on Atmospheric Electricity, June 308, 1984. Albany, NY. American Meteorological Society, Boston.
Miller, G.; Redders, J.; Stein, R.; Edwards, M.; Phillips, J.; Andrews, V.; Sebring, S.; Vaandrager, C. 1993. Terrestrial Ecosystem Survey of the Santa Fe National Forest. USDA Forest Service Southwestern Region, Albuquerque. 563 pp.
Molles, M.C., Jr.; Dahm, C.N.; Crocker, M.T. 1992. Climatic variability and streams and rivers in semi-arid regions. pp. 197-202. In: R.D. Robarts and M.L. Bothwell (eds.). Aquatic Ecosystems in Semi-arid Regions: Implications for Resource Management. NHRI Symposium Series 7, Environment Canada, Saskatoon.
Moran, J.M.; Morgan, M.D. 1995. Essentials of Weather. Prentice Hall, Englewood Cliffs, NJ. 351 pp.
Morris, W.S.; Haggard, K.W.; Bahm, R.J.; Fosdick, E.K.; Crow, L.W. 1985. New Mexico Climate Manual: Solar and Weather Data. NMERDI 2-72-4523. New Mexico Energy Research and Development Institute, Santa Fe.
Neilson, R.P. 1986. High-resolution climatic analysis and southwest biogeography. Science 232:27-34.
Odum, E.P. 1993. Ecology and our Endangered Life-Support System. Sinauer Associates, Inc., Sunderland, MA. 301 pp.
Pavlik, B..M.; M.G. Barbour. 1991. Seasonal patterns of growth, water potential and gas exchange of red and white fir samplings across a montane ecotone. Am. Midl. Nat. 126:14-29.
Pipegrass, M.V.; Krider, E.P.; Moore, C.B. 1982. Lightning and surface rainfall during Florida thunderstorms. J. Geophys. Res. C (13):11,193-11,201.

Risser, P. 1991. Impacts of climate change and variability on ecological systems. pp. 27-30. In: The Rio Grande Basin Climate Change Scenarios, Proceedings of Workshops and Conference June 1-2, 1990, Albuquerque, NM. WRRI Rept. M24, Las Cruces, NM.

Sala, O.E.; Lauenroth, W.K. 1982. Small rainfall events: an ecological role in semiarid regions. Oecologia (Berlin) 53:301-304.

SAS Institute Inc. 1988. SAS/STAT User's Guide, Release 6.03 Edition. SAS Institute, Inc., Cary, NC. 1028 pp.

Scuderi, L.A. 1993. A 2000-year tree ring record of annual temperatures in the Sierra Nevada Mountains. Science 259:1433-1436.

Silvertown, J; M.E. Dodd; K. McConway; J. Potts; M. Crawley. 1994. Rainfall, biomass variation, and community composition in the Park Grass Experiment. Ecology 75(8):2430-2437.

SPSS Inc. 1990. SPSS/PC+ 4.0 Base Manual for the IBM/PC/XT/AT and PS/2. SPSS Inc., Chicago.

Star, J.; Estes, J. 1990. Geographic Information Systems: An Introduction. Prentice Hall, Englewood Cliffs, N.J.

Stensrud, D.J.; R.L. Gall; S.L. Mullen; K.W. Howard. Model climatology of the Mexican monsoon. Journal of Climate 8(7):1775-1794.

Swetnam, T.W.; Baisan, C.H. 1995. Historical fire regime patterns in the southwestern United States since AD 1700. In: Allen, C.D. (ed). Proceedings of the 2nd La Mesa Fire Symposium, March 29-31, 1994, Los Alamos, NM. National Park Service Technical Report Series. In Press.

Tidwell, P. 1995. pers. comm. USDA Forest Service, Mt. Taylor District, Grants, NM.

Tuan, Y.; Everard, C.E.; Widdison, J.G. 1969. The Climate of New Mexico. State Planning Office, Santa Fe. 169 pp.

U.S. Department of Agriculture, Forest Service. 1986. Terrestrial Ecosystem Survey Handbook. Southwestern Region. USDA Forest Service, Albuquerque.

___. 1993. Summary National Hierarchical Framework of Ecological Units. ECOMAP, USDA Forest Service, Washington, D.C. 20 pp.

___. 1994a. Pole Canyon Ecosystem Management Area, Terrestrial Ecosystem Survey Interpretations. USDA Forest Service, Cibola National Forest, Mt. Taylor Ranger District (unpub. paper).

___. 1994b. Research Program Description: Ecology, Diversity, and Sustainability of Soil, Plant, Animal and Human Resources of the Rio Grande Basin. Rocky Mountain Forest and Range Experiment Station, Albuquerque. 32 pp.

United States Department of Commerce, National Oceanic and Atmospheric Association. 1982. Experimental lightning detection charts help locate thunderstorms. Western Region Technical Attachment No. 82-32. National Weather Service. 5 pp.

___. 1988. Surface Observations. U.S. Office of Federal Coordinator for Meteorological Services and Supporting Research. U.S. Department of Commerce, NOAA, Rockville, MD.

___. 1992-1994. Climatological Data, NM. National Oceanic and Atmospheric Association, Environmental Data Services, National Climatic Data Center, Asheville, NC.

U.S. Department of Interior, Bureau of Reclamation. 1994 (draft). Rio Puerco Sedimentation and Water Quality Study: An Appraisal Evaluation of the Impacts of the Rio Puerco on the Rio Grande and Elephant Butte Reservoir. USDI Bureau of Reclamation, Albuquerque.

University Corporation for Atmospheric Research. 1994. El Niño and Climate Prediction. Reports to the Nation on Our Changing Planet. UCAR Office for Interdisciplinary Earth Studies. 25 pp.

Venkatram, A. 1988. On the use of kriging in the spatial analysis of acid precipitation data. Atmospheric Environment 22(9):1963-1965.

Vorpahl, J.A.; Sparrow; J.G.; Ney, E.P. 1970. Satellite Observations of Lightning. Science 169:860-862.

Walker, D.A.; J.C. Halfpenny; M.D. Walker; C.A. Wessman. 1993. Long-term studies of snow-vegetation interactions. BioScience 43(5):287-301.

Watts, R.D.; Fox, D.G.; DeCoursey, D.; Goonan, T. 1994. Arroyo Dynamics of the Rio Puerco Basin: TERRA Work Plan. Terrestrial Ecosystem Regional Research and Analysis Laboratory, Ft. Collins.

Yeakley, J.A.; R.A. Moen; D.D. Breshears; M.K Nungesser. 1994. Response of North American ecosystem models to multi-annual periodicities in temperature and precipitation. Landscape Ecology 9(4):249-260.

Zar, J.H. 1974. Biostatistical Analysis. Prentice Hall, Inc., Englewood Cliffs, N.J. 620 p.

Flow of water and sediments through Southwestern riparian systems

Leonard F. DeBano[1], Peter F. Ffolliott[1], and Kenneth N. Brooks[2]

Abstract.—The paper describes streamflow, sediment movement and vegetation interactions within riparian systems of the southwestern United States. Riparian systems are found in a wide range of vegetation types, ranging from lower elevation desert environments to high elevation conifer forests. The climatic, vegetative and hydrologic processes operating in the southwestern environments provide a unique setting for discussing riparian ecosystem interactions with both water and sediment. Most streamflow at lower elevations is intermittent, and riparian vegetation frequently occupies channels that are dry at least part of the year. As a result, water table fluctuations in relation to streamflow and their subsequent effects on the establishment and maintenance of healthy riparian vegetation are key processes. At higher elevations, streamflow from snowmelt and rainfall is sufficient to sustain perennial streamflow and thereby provides a more consistent source of water for riparian vegetation. At all elevations, precipitation fluctuates widely, with many high-intensity, localized, convection storms occurring during the summer. As a result of this highly variable precipitation-runoff regime, erosion in the southwestern United States is an unsteady or discontinuous process that transports sediment from source areas through a channel system with intermittent periods of storage. This episodic transport process is characteristic of drylands in the southwestern United States where big storms are the prime movers of sediment. Intermittent streamflow coupled with the discontinuous storage and subsequent movement of sediment through channel systems in response to fire and other disturbances is extremely complex, and can be difficult to interpret when assessing responses of southwestern riparian systems to management.

INTRODUCTION

Riparian systems are defined as geographically delineable areas with distinct resource values and with characteristics which are comprised of both aquatic and terrestrial components (DeBano and Schmidt, 1989a). Riparian systems stabilize stream channels, provide repositories for sediment, serve as nutrient sinks for surrounding watersheds, and improve the water quality. They also provide water temperature control through shading, reduce flood peaks, and serve as recharge points for renewing ground water supplies. Considerable effort has been concentrated on vegetation structure and classification, plant succession, water consumption, and grazing-wildlife interactions in riparian systems. Only recently, however, have managers become aware of the beneficial effect that different watershed practices have on enhancing existing riparian systems or restoring degraded areas (DeBano et al. 1984, DeBano and Hansen

[1] *School of Renewable Natural Resources, University of Arizona, Tucson, AZ.*

[2] *College of Natural Resources, University of Minnesota, St. Paul, MN.*

1989, DeBano and Heede 1987, Szaro and DeBano 1985). As a result, research is now focusing not only on the riparian systems themselves, but also on the possible linkages between the riparian systems and the watersheds in which they occur.

This paper presents an overview of the Southwest environment and describes streamflow, sediment movement and vegetation interactions within riparian systems of the southwestern United States. Phreatophyte communities, such as salt cedar, are not considered.

ENVIRONMENT AND HYDROLOGY

The climatic, vegetative, and hydrologic processes operating in the southwestern United States provide a unique setting for discussing land and riparian area interactions with both water and sediment. This dry-land environment and resulting landscape patterns engender issues that are different from those encountered in more humid climates.

Vegetation

Vegetation types traversed while moving from the dry lowlands to higher elevations in the southwestern United States are desert, semi-desert, chaparral, pinyon-juniper, ponderosa pine, mixed conifer-aspen, and mountain grasslands at the higher elevations. Riparian systems are found in all these vegetation types.

Climate

The mean annual precipitation varies from 0.1 mm in the low-lying deserts to over 750 mm at higher elevations in mixed conifer forests (Hibbert et al. 1974). The low precipitation in some areas is further complicated by large temporal and spatial variability (Renard et al. 1985). In these low elevation areas, the total precipitation can occur during a few months as high intensity rainstorms, leading to frequent periods of drought. On the average, about 55% of the annual precipitation in the central Arizona mountains falls as rain or snow between November and April (Hibbert et al. 1974). Although their intensity is relatively low, these winter storms can release large amounts of water. Another 35% of the annual precipitation occurs during July, August, and September from local convection storms, which are often intense and erratic. Unusual storms during this period play a major role in erosion and sedimentation and have a disproportionate influence on the results of short-term studies. The remaining 10% of rain falls in May, June, and October, which are the driest months and of least importance hydrologically.

Streamflow

Water is usually in short supply during most of the growing season and only at higher elevations does sufficient precipitation occur to sustain perennial streamflow. Most streams in the lower desert grasslands, desert shrub, chaparral, and pinyon-juniper woodlands are ephemeral, flowing only in the winter or infrequently in response to high-intensity, localized convection-type storms during the summer. Potential evapotranspiration generally exceeds precipitation in the lower elevation vegetation types. Although streamflow can be intermittent at the lower elevations, riparian vegetation frequently occupies channels that are dry at least part of the year. At higher elevations in ponderosa pine and especially mixed conifer forests, rainfall and snowmelt are sufficient to sustain perennial streamflow, providing a more consistent source of water for riparian vegetation.

Sediment movement and channel dynamics

Erosion is an unsteady or discontinuous process which transports sediment from a source area through a channel system with intermittent periods of storage (Wolman 1977). This episodic transport process is characteristic of arid or semiarid climates, because the prime mover of erosion is the big storm. Consequently, most sediment in the southwestern United States is transported in riparian systems during major streamflow events. The storage and subsequent movement of sediment through channel systems in response to fire or other disturbances are complex (Heede et al. 1988). Other factors such as loss of plant cover by poor management practices or fire may also produce high amounts of surface runoff which are concentrated in the channels and move sediment,

even during smaller storms. Many of the factors responsible for sediment transport are interrelated, complex, and difficult to quantify.

Both vegetation and topography interact to move and store sediment within these intermittent stream systems. The primary role of vegetation in regulating sediment is the slowing down of the stream flow and the dissipating of energy which allows the water to infiltrate into the stream bank and recharge nearby groundwater. This increased infiltration prevents excessive erosion and maintains the physical stability of the landscape, which in turn provides moisture to the stream banks and, thereby, encourages the establishment of riparian vegetation (DeBano and Schmidt 1989a).

The hillslopes are a major source of sediment in the southwestern fluvial systems. The sediment detached by rainfall and runoff is transported from these upland areas during major storm events. Denudation of the vegetative cover, due to grazing, logging, or other disturbances, accelerates erosion and increases the sediment yield of the system. In intermittent systems, this sediment is often deposited in the channel until a sufficiently large streamflow event occurs, which moves it further downstream. Sediment can be stored in the channel for many years, making it difficult to interpret the sediment generating process on the surrounding hillslopes (Heede et al. 1988). Although suspended sediment is the largest portion of the total sediment moved (in many cases over 90%), the bedload component plays an important role in channel structure and function. This unsteady movement of sediment (involving both aggradation and degradation) also figures heavily into the stability of downstream riparian systems.

Riparian-watershed linkages

In the southwestern United States, erosion and runoff processes are key factors affecting the stability of lands both within riparian systems and on the surrounding hillslopes. Sediment movement in riparian systems is controlled by vegetation, topography, and hydrology, along with the degree of control exerted by stable geologic formations. If riparian systems are in dynamic equilibrium, the volumes of incoming sediment equal those of outgoing sediment. In this condition, the riparian vegetation remains vigorous but does not encroach into the active mean annual flood channel, nor does streamflow rapidly expand stream meander cutting or growth of point bars through the riparian area, nor impact it by eroding the channel bed.

This equilibrium between channel deposition (aggradation) and downcutting (degradation) by erosion in channels was initially described by (Lane 1955), with the discussion later expanded by Heede (1980) to describe changing streams. The concept was later applied to the health of riparian systems (DeBano and Schmidt 1989a). A healthy riparian system is one that maintains a dynamic equilibrium between streamflow forces acting to produce change and vegetative, geomorphic, and structural resistance. When this natural riparian system is in dynamic equilibrium, it is sufficiently stable so that compensating internal adjustments can occur without significantly altering this equilibrium. This resilience, or resistance to rapid change, results from the internal adjustment among several factors operating simultaneously in the riparian system (vegetation, channel depth, stream morphology, etc.) to increased flow or sediment movement. For example, excessive short-term runoff from the upland watershed can increase channel flow volume and velocity, which in turn causes channel erosion and deposition rates in a downstream riparian community. Under these conditions, the system oscillates back and forth, and can be quickly dampened by internal adjustments so that no major change occurs in the dynamic equilibrium of the riparian system. When the resilience or elasticity of the system is not violated, a new equilibrium condition can be established which continues to support a healthy riparian area. Flows in excess of channel capacity frequently overflow onto floodplains where riparian vegetation and associated debris provide a substantial resistance to flow and act as filters, or traps, for sediment. During these bank overflows, opportunities are available for germination and establishment of certain riparian plant species (Brady et al. 1985).

OTHER WATERSHED CONSIDERATIONS

In addition to most common hydrologic processes, other watershed variables are important

when discussing riparian systems. These are organic debris and instream flow.

Large organic and woody debris

Large organic debris and large woody debris are becoming recognized as increasingly important components of watersheds and river systems. Studies of ephemeral and perennial streams in the southwestern United States revealed that woody debris plays an important role in sediment transport and channel processes (Minckley and Rinne 1985). Channels of mountain streams contain numerous log steps and transverse gravel bars that dissipate energy and reduce average channel gradients of "rushing mountain streams" by 8 to 22% (Heede 1972). In perennial streams, 70 to 96% of the total channel gradient can be made up by the cumulative height of these steps. The greater the proportion of the total drop made up by steps and gravel bars, the more energy dissipated and the less sediment moved. Also, definite inverse relationships exist between the number of log steps and gravel bars in perennial streams, so when more log steps are present fewer gravel bars are formed (Heede 1972). These studies indicate that more sediment is moved when fewer log steps are available. Forest density determines the proportion of logs incorporated into the stream hydraulic system, which in turn affects bedload movement (Heede 1977).

Large organic debris consists of any piece of relatively stable woody material having a diameter greater than 10 cm and a length greater than 1 meter that intrudes into the stream channel (Amer. Fish. Soc. West. Div. 1985). Large woody debris is similar but refers specifically to rootwads and tree stems which provide overhead cover and flow modifications for effective spawning and rearing habitat of anadromous and resident fishes (Bisson et al. 1981).

Forest ecosystems adjacent to streams are the main source of large debris. Several mechanisms are responsible for transferring large woody debris into stream channels: bank undercutting and collapse; tree blowdown; tree collapse from snow or ice; snow avalanches; and mass soil movements. These processes transfer large pieces of wood from forests to stream channels in either frequent and irregular intervals in time and space, or episodically when large inputs are infrequently spaced. The more frequent input processes include tree mortality from disease and insects combined with windthrow or gradual stream undercutting of root systems. Episodic inputs are induced by large-scale epidemics of insects or diseases, extensive blowdown, logging, debris avalanches, and massive erosion during major floods.

Large woody debris plays an important role in the hydraulics, sediment routing, and channel morphology of streams flowing through forest ecosystems (Smith et al. 1993). The effects of large woody debris occur randomly in space, owing to randomly occurring processes of delivery from the adjacent riparian zone, such as wind throw, stem breakage, and bank erosion. Large woody debris constitutes an important element of hydraulic resistance in forest streams, the effectiveness of which varies with debris size and spacing. Large woody debris affects channel morphology and sediment routing and contributes in major ways to the formation and quality of habitat for aquatic organisms. In this environment, the dense vegetative canopies help keep waters cool, and falling tree litter delivers nutrients to the stream portion of the ecosystem. Large organic debris and fallen trees can amount to 80-280 metric tons/ha and greatly influence the physical and biological characteristics of small streams (Sedell et al. 1988.)

Woody debris increases the complexity of stream habitats by physically obstructing water flow. Trees extending partially across the channel deflect the current laterally, causing it to widen the streambed. Sediment stored by debris also adds to hydraulic complexity, especially in organically rich channels that are often wide and shallow and possess a high diversity of riffles and pools in low gradient streams of alluvial valley floors. Even if the stream becomes so large that trees cannot span the main channel, debris accumulations along the banks cause meander cutoffs and create well-developed secondary channel systems. Debris also creates variation in channel depth by producing scour pools downstream from obstructions. Wood, therefore, maintains a diverse physical habitat by: anchoring the position of the pools along the direction of the stream; creating backwaters along the stream margin; causing lateral migration of the channel and forming secondary channel systems in alluvial valley floors; and increasing depth variability.

Instream flow

Within the last two decades, the concept of instream flow has become an important consideration in watershed management and, likewise, in the management of riparian systems in the western United States. Almost all the water in western streams has been appropriated for a wide range of uses outside the stream channel (agriculture, domestic, etc.). Recently, however, the water that remains within streams is becoming recognized as having an important value. The sustainability of riparian systems along streams is an excellent example of a valuable instream flow use of water.

Instream flow is basically the streamflow regime required to satisfy a mixture of conjunctive demands being placed on water while it is in a stream (Amer. Fish. Soc. Wes. Div. 1985). Instream flow requirements are, therefore, the amounts of water flowing through a stream course that are required to sustain instream values at some predetermined level. Instream flow rights are legal entitlements to use surface water within a specified area of a stream channel for fish, wildlife, or recreation uses. This use must be non-consumptive except for the normal needs of wildlife and vegetation. An instream flow right protects a designated flow, through a specified reach of a stream, from depletion by new water users; this right is especially important where new upstream uses, developments, diversions or transfers could threaten existing flows. The benefits of instream flow rights include protection of fish and the diversity of riparian plants and animals that live in or along the water, including threatened and endangered species (Kulakowski and Tellman 1990).

CURRENT STATUS

The impact of past (late 1800's) extensive, unmanaged livestock grazing, wildfires, and forest clearing, coupled with numerous localized perturbations such as travelways, low standard roads, and livestock trails, has dramatically influenced the status and function of riparian systems. Vegetation removal and soil compaction substantially increased surface runoff, produced sediment-laden flows, and increased erosive power in the channel system. The cumulative effects of these actions have altered riparian systems and the linkages between uplands and stream channels (LaFayette and DeBano 1990). The above runoff and erosion scenario has led to the degradation, channel incision, and, in some cases, complete destruction of many riparian systems. A key factor in improving deteriorated riparian systems is understanding the balance that existed between watershed condition and riparian health in near pristine conditions. Under such conditions, watershed slopes and riparian channels were able to dissipate rainfall and concentrate flow energies produced during different precipitation events.

A comprehensive review synthesis of existing information on riparian systems in the Southwest has been published (DeBano and Schmidt 1989a). This synthesis indicates that numerous opportunities are available for better managing existing southwestern riparian systems, and creating hydrologic regimes more favorable for rehabilitating existing, or creating new, riparian ecosystems (DeBano and Schmidt 1989b). Although much of the technology is available for rehabilitating and restoring badly depleted riparian systems (Heede 1980), many key science questions and research needs still remain.

FUTURE OF SOUTHWESTERN RIPARIAN SYSTEMS

Interest in, and concern for, riparian systems will continue to grow because significant amounts of these systems have already been lost. Although the estimates of loss of riparian systems in the Southwest vary widely, the greatest loss has occurred along the banks of the larger river systems that flow through the lower elevation deserts (e.g., Salt and Gila Rivers). The early settlers cleared large expanses of the riparian vegetation during settlement along these large rivers (Carothers 1977). Also, a less desirable introduced tree, salt cedar, has replaced many of the native cottonwood galleries along the lower elevation rivers. The higher elevation riparian systems in the Southwest have fared much better; it is estimated that only about 30 to 35% of these riparian systems have been lost (Dahl 1990). Although riparian systems occupy only about 1% of the land area in the Southwest, they are an extremely valuable for

wildlife and fish habitat, recreation, maintaining landscape diversity, sediment filtering and flood reduction, points of recharge for ground water, commercial timber, and sustainable forage for domestic livestock and wildlife. Therefore, a sense of urgency exists to not only preserve existing riparian systems, but also to develop an aggressive program for rehabilitating existing riparian systems that have been badly depleted.

LITERATURE CITED

American Fisheries Society, Western Division, Habitat Inventory Committee (William T. Helm, Editor). 1985. Aquatic habitat inventory: Glossary and Standard Methods. p. 1-34.

Bisson, Peter A; Nielsen, Jennifer L; Palmason, Ray A.; Grove, Larry E. 1981. A system of naming habitat types in small streams, with examples of habitat utilization by salmoids during low streamflow. p.62-73. In: Symposium on Acquisition and Utilization of Aquatic Habitat Inventory Information. October 28-30, 1981. Portland, OR.

Brady, W.; Patton, D. R.; Paxson, J. 1985. The development of southwestern riparian gallery forests. In: Johnson, R. R.; Ziebell, C. D.; Patton, D. R.; Ffolliott, P. F.; Hamre, R. H., tech. coords. Riparian ecosystems and their management: reconciling conflicting uses: First North American Riparian Conference; 1985 April 16-18; Tucson, AZ. Gen. Tech. Rep. RM-120. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 39-43.

Carothers, Steven W. 1977. Importance, preservation and management of riparian habitat: An overview. In: Johnson, R.R.; Jones, D.A., tech. coords. Importance, preservation and management of riparian habitat, a symposium; Gen. Tech. Rep RM-43. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 2-4.

Dahl, T.E. 1990. Wetlands losses in the United States 1780's to 1980's. U.S. Department of Interior, Fish and Wildlife Service, Washington, D.C. 21 p.

DeBano, L. F.; Brejda, J. J.; Brock, J. H. 1984. Enhancement of riparian vegetation following shrub control in Arizona chaparral. Soil and Water Conservation. 39: 317-320.

DeBano, Leonard F.; Hansen, William R. 1989. Rehabilitating badly depleted areas using channel structures. In: Practical approaches to riparian resource management; 1989 May 8-11; Billings, MT. Billings, MT: U.S. Bureau of Land Management: 141-148.

DeBano, Leonard F.; Heede, Burchard H. 1987. Enhancement of riparian ecosystems with channel structures. Water Resources Bulletin. 23: 463-470.

DeBano, Leonard F.; Schmidt, Larry J. 1989a. Improving southwestern riparian areas through watershed management. Gen. Tech. Rep. RM-182. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 33 p.

DeBano, Leonard F.; Schmidt, Larry J. 1989b. Interrelationship between watershed condition and riparian health. In: Practical approaches to riparian resource management; 1989 May 8-11; Billings, MT. Billings, MT: U.S. Bureau of Land Management: 45-52.

Heede, Burchard H. 1972. Influences of a forest on the hydraulic geometry of two mountain streams. Water Resources Bulletin. 8: 523-530.

Heede, Burchard H. 1977. Influence of forest density on bedload movement in a small mountain stream. Hydrology and Water Research in Arizona and the Southwest. 7: 103-107.

Heede, Burchard H. 1980. Stream dynamics: an overview for land managers. Gen. Tech. Rep. RM-72. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 26 p.

Heede, Burchard H.; Harvey, Michael D.; Laird, Jeffrey R. 1988. Sediment delivery linkages in a chaparral watershed following a wildfire. Environmental Management. 12: 349-358.

Hibbert, Alden R.; Davis, Edwin A. D.; Scholl, David G. 1974. Chaparral conversion potential in Arizona. Part I: Water yield response and effects on other resources. Res. Pap. RM-126. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 36 p.

Kulakowski, Lois; Tellman, Barbara. 1990. Instream flow rights: A strategy to protect Arizona's streams. Water Resources Research Center Issue Paper 6. University of Arizona, Tucson, AZ. 25 p.

LaFayette, Russell A.; DeBano, Leonard F. 1990. Watershed condition and riparian health: Linkages. In: Watershed planning and analysis in action: Symposium proceedings of Irrigation Conference; 1990 July 9-11; Durango, CO. New York, NY: Watershed Management/Irrigation Division, American Society of Civil Engineers: 473-484.

Lane, E. W. 1955. The importance of fluvial morphology in hydraulic engineering. Proceedings of the American Society of Civil Engineering, Journal of the Hydraulics Division. 81: 745-1 to 745-17.

Minckley, W. L.: Rinne, John J. 1985. Large woody debris in hot-desert streams: a historical review. Desert Plants 7: 142-153.

Renard, K. G.; Cox, J. R.; Post, D. F. 1985. Effects of soil erosion on productivity in the Southwest. Chapter 19. In: Follett, R. F.; Stewart, B. A., eds. Soil erosion and crop productivity. American Society of Agronomy, Inc., Crop Science Society of America, Inc., and Soil Science Society of America, Inc., Madison, WI: 321-326.

Sedell, James,R.; Bisson, Peter A.; Swanson, Frederick, J.; Gregory, Stanley V. 1988. Chapter 3: What we know about large trees that fall into streams and rivers. p. 47-81. In: From the forest to the sea: A story of fallen trees. Maser, Chris; Tarrant, Robert F.; Trappe, James M.; Franklin, Jerry F. (Tech. Eds.). USDA Forest Service General Technical Report PNW-GTR-229. Pacific Northwest Forest and Range Experiment Station, Portland, OR. 153 p.

Smith, R.D.; Sidle, R.C.; Porter, P.E.; Noel, J.R. 1993. Effects of experimental removal of woody debris on the channel morphology of a forest, gravel-bed stream. Journal of Hydrology 152:153-178.

Szaro, R. C.; DeBano, L. F. 1985. The effects of streamflow modification on the development of a riparian ecosystem. In: Johnson, R. R.; Ziebell, C. D.; Patton, D. R.; Ffolliott, P. F.; Hamre, R. H., tech coordinators. Riparian ecosystems and their management: reconciling conflicting uses: First North American Riparian Conference; Gen. Tech. Rep. RM-120. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station: 211-215.

Wolman, M. Gordon. 1977. Changing needs and opportunities in the sediment field. Water Resources Research. 13: 50-54.

Effects of livestock grazing on nutrient retention in a headwater stream of the Rio Puerco Basin

Mark A. Sewards[1] and H. Maurice Valett[2]

Abstract.—Sediment and nutrient loss from headwater streams of sedimentary basins in the semi-arid Southwest have been attributed to both over-grazing by livestock and to climatic cycles that influence arroyo formation. Considerable effort has been directed toward the influence of livestock grazing on riparian species abundance and diversity. Less work has concentrated on the influence of livestock on in-stream processes and communities. In contrast, considerable research has described the importance of floods as ecological organizers of riparian and benthic communities in lotic ecosystems. Here, we consider the interaction of flooding and livestock grazing on hydrologic and nutrient retention in a headwater stream of the Rio Puerco Basin, NM. We propose that grazing decreases retention of water, sediments, and nutrients by changing physical and biological features of the stream that cause the system to be less resistant to natural floods and by decreasing recovery rates when floods do occur (i.e. less resilience). This work presents our initial studies of the differing nutrient and hydrologic environments created by cattle exclosures on the Rio Señorito, a tributary of the Rio Puerco. Preliminary results indicate that benthic biomass and transient hydraulic storage are greater in reaches protected from cattle influences. Finally, we propose a conceptual model that predicts the implication of disturbance interaction for streams impacted by flash floods and grazing practices.

INTRODUCTION

Livestock grazing is the most widespread land-use practice in the Southwest (Lusby et al. 1971, Wagner 1978, Crumpacker 1984, Fleischner 1994). In semi-arid environments, the effects of grazing are concentrated in riparian zones and environmental impacts include increased bank erosion (Szaro 1989) and sediment transport (Lusby et al. 1971), soil compaction (Lusby et al. 1971, Fleischner 1994), loss of riparian species (Szaro 1989, Fleischner 1994), and decreased water quality (Szaro 1989).

Sediment transport is also influenced by arroyo formation in sedimentary basins. The most likely causes of arroyo formation include long term climatic cycles (i.e. flooding), livestock grazing and the interaction between these features (Mainguet 1994). Little is known about the effects of grazing on nutrient dynamics in streams impacted by arroyo formation. Biological and hydrologic processes that retard nutrient transport contribute to nutrient retention, a fundamental measure of stream ecosystem functioning (Vitousek and Reiners 1975, Grimm 1987). We propose that hydrologic and nutrient retention are useful indicators of ecosystem stability (resistance and resilience) in the face of disturbance by land

[1] *Graduate student in the Department of Biology, University of New Mexico, Albuquerque.*

[2] *Visiting Assistant Professor, Department of Biology, University of New Mexico, Albuquerque.*

use practices (i.e. livestock grazing) and natural flood events.

Flood events are one of the most common naturally occurring disturbances in semiarid stream and riparian ecosystems. Extensive mortality (a loss of biomass and diversity) of riparian and benthic organisms occurs (Gray and Fisher 1981), but communities recover and reorganize quickly (Campbell and Green 1968, Fisher et al. 1982, Grimm and Fisher 1989). Livestock grazing also causes mortality, but disturbance effects are more chronic (Fleischner 1994). Trampling and grazing removes biological retentive structures (e.g. plant cover or debris dams) which causes a loss of hydrologic, sediment, and nutrient retention (Szaro 1989, Trotter 1990, Fleischner 1994).

In southwestern streams, temporal organization of flooding and grazing disturbances affects ecosystem structure and function for aquatic and riparian subsystems. Floods occur as a result of natural annual climactic cycles during spring runoff and late summer monsoons (Graff 1988, Molles and Dahm 1990). Historically, southwestern riparian and benthic species have adapted to survive seasonal flood events (Campbell and Green 1968). They may, however, be less well adapted to human-organized livestock grazing (Szaro 1989).

Timing of livestock grazing is dictated by human concerns and often leads to constant land use. As a result, livestock may impact organisms and processes during times when they must also recover from natural flood disturbance. The extent of ecological damage to semi-arid southwestern ecosystems is related to the change in species type and population densities of grazers. Historically, effects of trampling were minimal because natural grazers existed in these ecosystems at low population densities (Hastings 1959, Cooper 1960, Fleischner 1994). During modern livestock grazing, high populations are maintained, and overgrazing often occurs. Many have argued that overgrazing has lead to incision and arroyo formation. Mainguet (1994) specifically describes the Rio Puerco basin in a case study implicating livestock grazing as a primary cause of erosion, arroyo formation, and sediment loss. Because of its physical impact on stream beds, its influence on vegetation and its impact on hydrologic characteristics of streams, livestock grazing may be the primary determinant of sediment and nutrient transport in streams draining sedimentary basins in the semi-arid Southwest.

RESEARCH OBJECTIVES

This research focuses on how livestock activity and annual flood events influence nutrient retention in headwater streams of the Rio Puerco basin that are impacted by arroyo formation.
We hypothesize that by disturbing in-stream communities and reducing riparian biomass and diversity, livestock grazing results in lower nutrient retention and lowers stability to annual flood events. Regions of the stream protected from grazing influences are predicted to be more resistant to flood events and also recover more rapidly. Our preliminary research goals included:

1. Mapping of reach type and distribution along the Rio Señorito,
2. A survey of the nutrient concentrations in surface and groundwater, and
3. Characterization of the hydrologic storage in reaches representative of exclosures and wátering gaps (i.e. reaches where cows have access to the stream). Here we report on the results of these initial projects.

STUDY SITE

Land-use practices along the Rio Puerco, a tributary of the Rio Grande in north central New Mexico, are of particular interest because the Rio Puerco has one of the highest suspended sediment loads of any river in the world (>267, 000 mg/L, Mainguet 1994). Our study site along the Rio Señorito (fig. 1) is located at the headwaters of the Rio Puerco where the Bureau of Land Management (BLM) has constructed four 600-meter grazing exclosures separated by three 200 meter gaps for watering livestock. Two grazing exclosures (exclosures # 1 & # 2) were installed in the winter of 1993, the third (#3) during the winter of 1994 and the fourth (#4) was completed in October of 1994. Thus, riparian communities in the four exclosures have been free of grazing for 3, 3, 2 and 1 growing seasons, respectively. The exclosures are

visibly more vegetated than the water gaps and species of forbs, grasses and willows are found in the active stream channel. The exclosures are part of an experimental management plan developed by the BLM to assess restoration and recovery of semi-arid riparian ecosystems from concentrated livestock grazing disturbance (Pers. Comm, Duane Vincent, Rio Puerco Resources Division, BLM, Abq, NM).

METHODS

Surface and Groundwater Biogeochemistry

The spatial distribution of exclosures and gaps (fig. 1) provides an excellent opportunity to experimentally determine the influence of livestock on nutrient retention in the Rio Señorito. Eventually, replicated treatments and control plots will be used as experimental units and comparative solute injections will be used to test the hypothesis that grazing and livestock disturbance decrease the retention of nutrients and sediments in the Rio Puerco headwaters.Here, we provide initial comparisons of "gap" and "exclosure" structure and function without relying on inferential statistics except when appropriate within experimental units.

The study site was mapped in December of 1994 using 100 m tapes walked along the stream bed. Measurement of total length and distribution of reach types (exclosures and gaps) were included in mapping efforts. At the time of mapping, stream water samples were collected at 100 m intervals and at the beginning and end of each gap and exclosure. Comparison of stream water nutrients (see below for nutrient analysis techniques) in gaps and exclosures were performed using ANOVA with reach type as a single factor with two levels (gap and exclosure).

In March of 1995, shortly after a high flow event, we established six sampling transects over 50 m within the stream in Exclosure #2 to assess longitudinal and vertical distribution of solutes in the Rio Señorito (fig. 2). Wells were constructed of 3/4" PVC pipe and were used to obtain water samples and as piezometers to determine the direction of vertical hydrologic exchange between the groundwater and stream. Positive hydraulic heads from these wells (data not presented) indicated that groundwater flowed vertically upward throughout the study reach. Wells were established to sample

Figure 1. Study site locations on the Rio Señorito, NM. Numbers refer to the "exclosures" (i.e. stippled polygons) that average 600 m length. Watering "gaps" are 250 m long and occur between the exclosures. The Rio Señorito enters the Rio Puerco just west of NM State Highway 44.

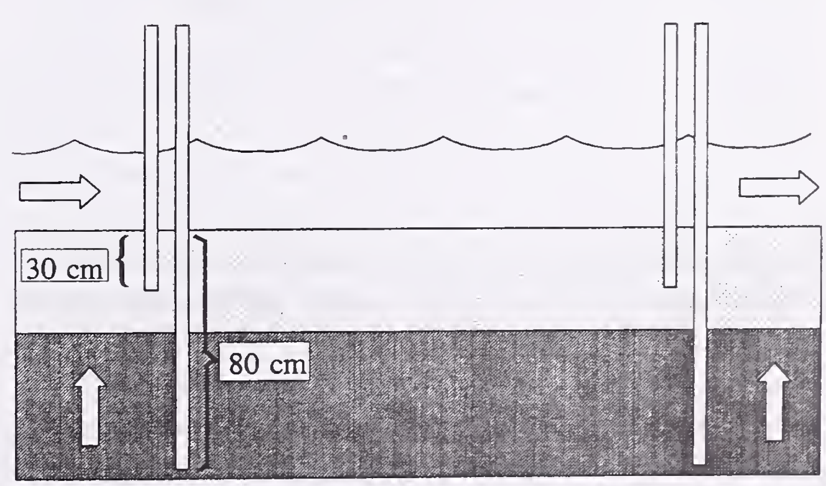


Figure 2. Schematic representation of water sampling transects established along a 50-m reach of exclosure #2. Wells were installed to sample shallow and deeper groundwater for biogeochemical characterization. Direction of water flow is denoted by the arrows.

surface water, shallow groundwater (depth = 20 cm) and deep groundwater (depth = 80 cm). This reach was also used for hydrological studies (see below).

Water samples were analyzed for biogeochemically active solutes including nitrate-nitrogen (NO_3-N), ammonium-nitrogen (NH^4-N), and phosphorous in the form of soluble reactive phosphate (SRP) using a Technicon Autoanalyzer II. NO_3-N was determined by colorimetric analysis following reduction to nitrite in a cadmium-copper column (Wood et al. 1967). The phenyl-hypochlorite method was used to measure NH_4-N (Soloranzo 1969) and we used the molybdate-antimony analysis to measure SRP (Murphy and Riley 1962). Dissolved oxygen (DO) was determined in well and surface water by the Winkler titration method. A Pearson correlation coefficient was calculated for DO and NO_3-N for samples collected from groundwater environments. Dissolved organic carbon (DOC) was determined by CO_2 evolution following persulfate oxidation (Menzel and Vacarro 1964) using an O.I. Corporation Model 700 TOC Analyzer.

Hydrologic Retention

During Summer of 1995, a 50 m reach was established in the water gap (Gap #1) adjacent to and upstream of Exclosure #2 where the previous 50 m reach was established for biogeochemical surveys. We hypothesized that livestock activities would reduce channel complexity and decrease hydrologic retention (i.e. result in less transient storage of water and solutes, Stream Solute Workshop, 1990). To assess differences in hydrologic retention, we estimated transient storage in the two reaches using solute injections of hydrologically-conservative tracers. In July of 1995, a single tracer injection was completed at each of the experimental reaches (i.e. first in the downstream reach within Exclosure #2 and then in the water gap immediately upstream). A sodium bromide (NaBr) solution of approximately 60 g/L was dripped into the stream at the top of each reach as a biologically and chemically unreactive (conservative) tracer. Before the injection, concentration of Br in surface water was approximately 100-150 ppb and the concentrated Br solution was added at a rate that increased in-stream concentrations to approximately 3 ppm for sixty minutes. Bromide levels were measured 50 m downstream of the injection site by collecting water samples for Br analysis at 15-second intervals until the solute reached a plateau concentration in the stream. Bromide concentrations were determined analytically using a Dionex DX-100 ion chromatograph.

Solute response curves generated from the time course of Br samples can be compared with theoretical square-wave responses that would have been observed if no dispersion or storage occurred during transport. We determined water velocity

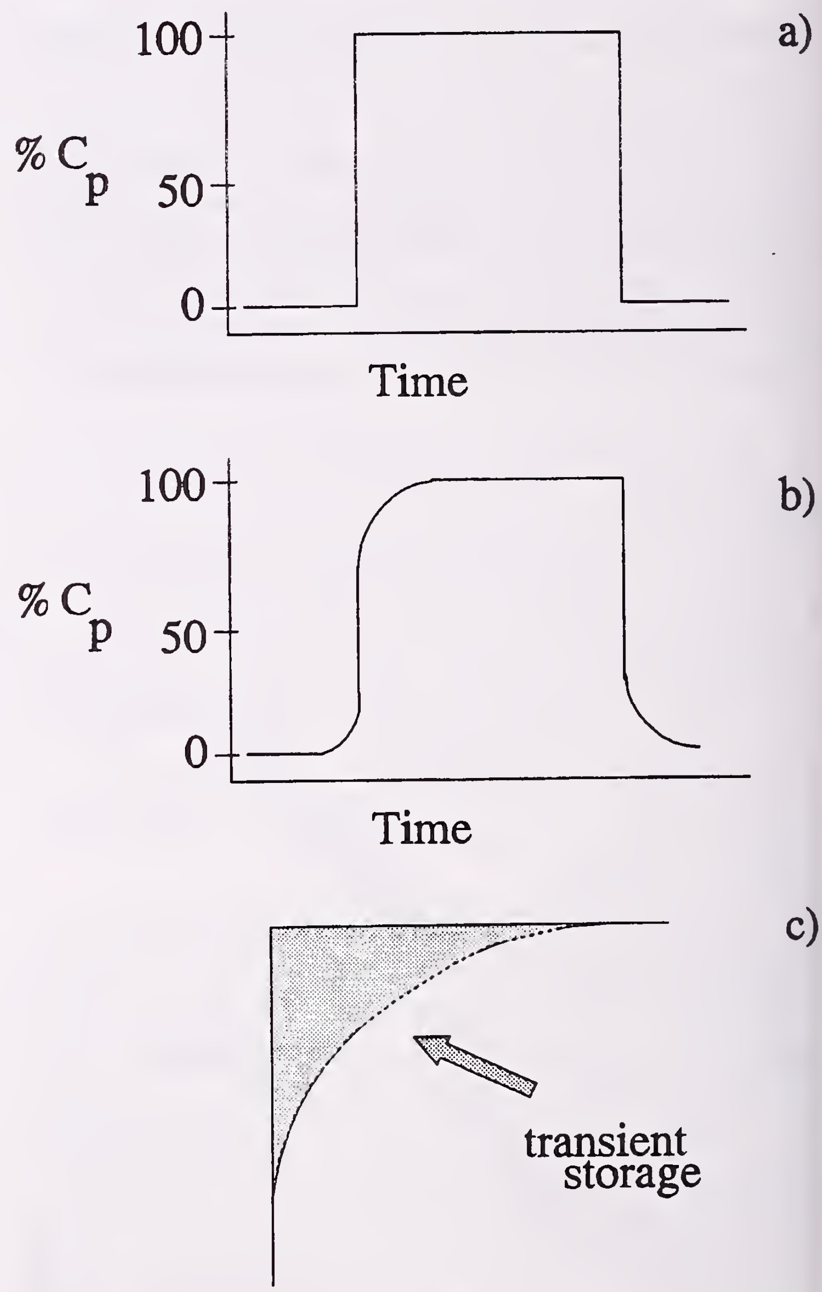


Figure 3. Typical solute-response curves generated during a tracer-addition experiment: a) the ideal square-wave curve that results if transport occurs without dispersion or transient storage, b) a curve more typical of empirical results illustrating the "rounding" produced by dispersion and storage, and c) the portion of the curve used to estimate transient storage. See text for further explanation.

from the nominal travel time (i.e. amount of time required for Br to reach half of its plateau concentration) and reach length. In addition, we estimated transient storage by determining the area generated when empirical solute response curves were superimposed on ideal curves (fig. 3, Stream Solute Workshop 1990). Areas were compared as a qualitative assessment of transient storage in the two reach types.

RESULTS

Concentrations of biogeochemically-active solutes did not differ significantly ($P > 0.05$) between gaps and exclosures during the longitudinal survey of December 1994. Surface water in gaps and exclosures was rich in NH_4-N, but NO_3-N in surface water was below detection level (Table 1). DOC concentrations were greater than 10 mg/L in each plot type and SRP concentrations were 8 and 7 ppb in gaps and exclosures, accordingly (Table 1). Atomic N:P ratios were high reflecting low SRP levels and plentiful NH_4-N.

During March of 1995, deep groundwater in the instrumented exclosure was rich in NH_4 -N (average concentration 300 ppb, fig. 4a), and concentrations dropped as water flowed upward towards the stream/groundwater interface. In contrast to the high concentrations observed in surface water during winter, surface NH_4-N concentrations were low (near detection level of ca. 10 ppb) during the spring survey. Conversely, while no NO_3-N was measured in surface water during winter, concentration averaged 135 ppb during spring sampling (fig. 4b). Nitrate-nitrogen in shallow and deep groundwater varied with distance downstream and ranged from less than 20 to more than 170 ppb (fig. 4b). Deep groundwater was generally anoxic, but only two of six shallow groundwater wells

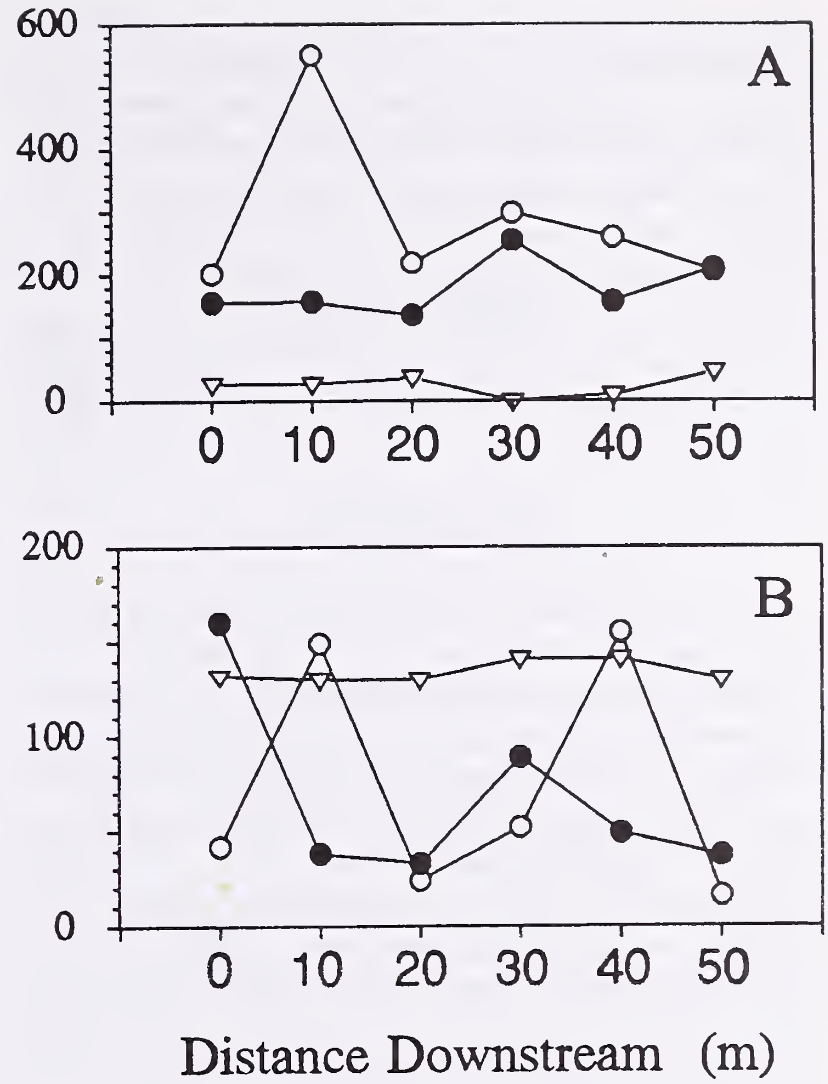


Figure 4. Inorganic nitrogen (ppb) in surface and groundwater during March of 1995: A) NH4-N and B) NO3-N in surface water (inverted triangles), shallow groundwater (filled circles, depth = 30 cm) and deep groundwater (open circles, depth = 80 cm).

lacked oxygen. Nitrate-nitrogen concentrations in groundwater were significantly correlated with DO content ($r = 0.55$, $P < 0.05$).

Solute injections carried out at each experimental reach illustrated differences in hydrologic transport and retention (fig. 5). Nominal travel times in the exclosure and gap reaches were ca. 16

Table 1. Selected stream water solute concentrations from Rio Señorito, NM. Data are means ± SE and were collected on December 19, 1994. Mean concentrations did not differ between grazed watering gaps and cattle exclosures (P > 0.05).

	NO_3-N (µg/L)	NH_4-N (µg/L)	SRP (µg/L)	DOC (mg/L)	N:P Ratios
Grazed Plots: (n =15)	0 ± 0	299 ± 61	8 ± 1	13.0 ± 5.0	82 ± 6
Exclosures: (n = 27)	0 ± 0	253 ± 20	7 ± 1	11.2 ± 3.2	104 ± 16’

and 19 min, respectively, corresponding to water velocities of 5.2 and 4.3 cm/s. Despite arriving earlier, solute concentrations in the exclosure were still rising after the injection was terminated sixty minutes after its initiation. In contrast, solute concentrations rose rapidly in the water gap and reached plateau abruptly after approximately 25 minutes of injection. Estimates of transient storage indicate that hydrologic retention in the exclosure was 4-5 times greater than in the adjacent water gap.

DISCUSSION

These preliminary results suggest that the Rio Señorito and other similar headwater streams of the Rio Puerco basin are spatially and temporally dynamic. Groundwater environments are anoxic and the fine mudstones that comprise the aquifer sediments are rich in NH_4-N. During winter, the stream is frequently ice-covered and in-stream and riparian communities are relatively inactive. Under these conditions, ammonium-rich sediments and groundwater contribute NH_4-N to the surface stream. In contrast, sediments are more biologically active during warmer times of the year and appear to be sites of nitrification as evidenced by the strong relationship between dissolved oxygen and NO_3-N in groundwater. Metabolically-active sediments may, therefore, account for the elevated NO_3-N and low NH_4-N in surface water during spring. At the time of sampling, surface water was turbid, and there were ample signs of a recent flood throughout the study reach. More extensive monitoring over time and among different reach types is necessary to determine if elevated NO_3-N concentrations reflect the influence of flooding or more long-term seasonal changes.

There were evident differences in the vegetational structure of exclosures and watering gaps. In addition to having greater cover of woody riparian species, stream-side herbaceous vegetation was extensive within the exclosures, and forbs often inundated the wetted channel making open water only rarely visible. In contrast, the experimental reach within the watering gap was sparsely vegetated, and stream-side banks were often bare of vegetation. Channel width was obviously greater

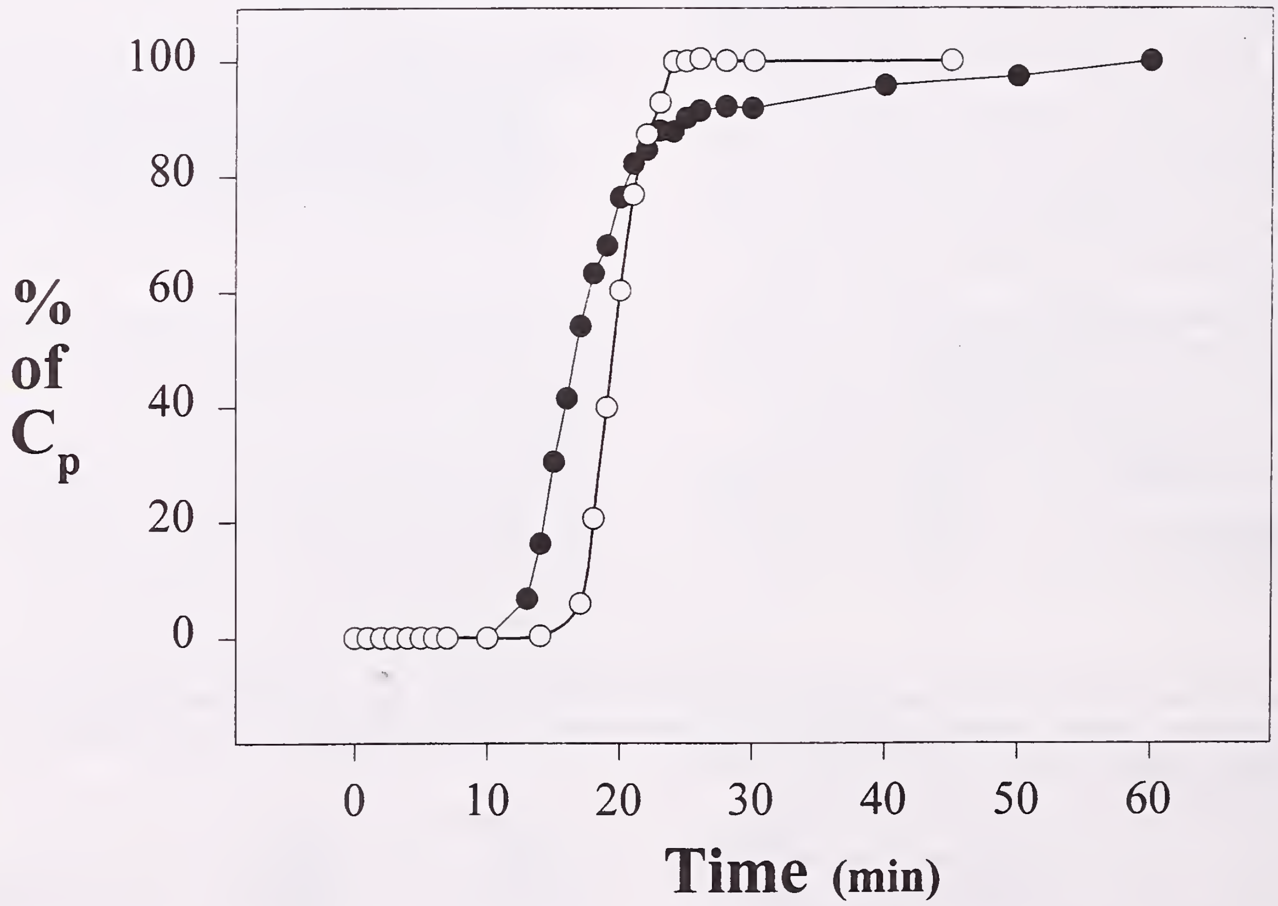


Figure 5. Solute response curves for the exclosure reach (filled circles) and for an adjacent reach in the watering gap (open circles). Values are plotted as percent of plateau concentration (% of Cp) against injection time.

in the water gap. Within the exclosure, channel width was reduced, and the wetted perimeter included a central deeper channel and shallow lateral areas heavily inundated by semi-aquatic vegetation. These differences in channel structure translated to different hydrologic behavior. Broader and shallower cross-sections within the watering gap resulted in slower water velocity (i.e. calculated velocity in the gap was ca. 83% of that in the exclosure). More restricted channel structure in the exclosure increased average linear velocity, but solute response curves clearly indicated that extensive areas of hydrologic storage existed in the exclosure and that these areas were lacking in the adjacent watering gap.

We propose that the lateral areas of shallow water that are inundated by vegetation are responsible for the transient storage measured in the exclosure. These lateral areas of increased residence time are crucial for increased biological processing and may also influence sediment transport and deposition. This is not the first study to suggest that grazing decreases the retention of water in semi-arid basins. Lusby et al. (1971) showed that eliminating livestock grazing in a western Colorado system decreased sediment and water yield to 66% of that in paired plots where grazing was continued. Their study, however, emphasized sediment and water yield in an intermittent wash. Our study suggests that grazing alters the hydrologic features of transport and retention in perennial systems by changing the physical and biological features that contribute to total retention.

CONCLUSIONS

Decreased plant cover, extensive areas of exposed sediments, and altered transport dynamics may make grazed reaches more susceptible to the effects of flash floods. In this context, flooding and grazing are expected to interact as natural and anthropogenic events to exacerbate disturbance in headwater streams of the Rio Puerco. Here we present a conceptual model (fig. 6) reflecting the interaction of livestock grazing and flash floods as ecological disturbances and provide three hypotheses regarding the differential functioning of grazed/non-grazed reaches. At any time, non-grazed reaches are expected to (1) exhibit greater retention than comparable reaches influenced by livestock. In addition, because of the decreased plant cover, watering gaps are predicted to be (2) less resistant to flash floods and these high flow events will more severely alter biological and geomorphic aspects of the stream channel.

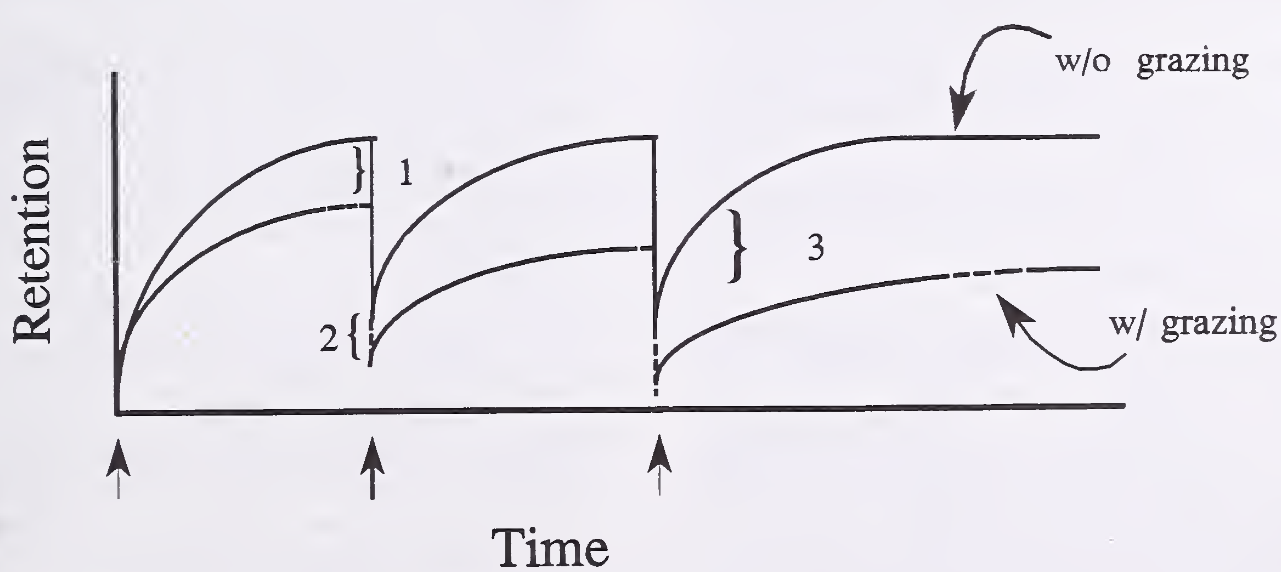


Figure 6. Conceptual model of disturbance interaction for streams impacted by floods and livestock grazing. Retention is plotted against time and flood events are depicted as arrows along the X-axis. 1) At any given time, grazed reaches (dashed line) are less retentive than reaches without grazing (solid line). 2) Because of pressure on biological and hydrologic agents of retention, grazed plots will be less resistant to flooding, and 3) rate of recovery (i.e. resilience) will be lower in grazed plots following disturbance by flash floods.

Finally, we hypothesize that successional responses to flash floods will be retarded by livestock grazing resulting in (3) lower resilience and contributing to decreased ecosystem stability.

ACKNOWLEDGMENTS

This study is funded by Cooperative Agreement No. 28-C4-833 with the USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

LITERATURE CITED

Campbell, C. J.; Green, W. 1968. Perpetual succession of stream-channel vegetation in a semi-arid region. Journal of the Arizona Academy of Science 5: 86-98.

Cooper, C.F. 1960. Changes in vegetation, structure and growth of southwestern pine forests since white settlement. Ecological Monographs 30: 129-164.

Crumpacker, D.W. 1984. Regional riparian research and a multi-university approach to the special problem of livestock grazing in the Rocky Mountains and Great Plains. Pages 413-422 in R.E. Warner, and K. Hendricks, editors. California riparian systems: ecology, conservation, and productive management. University of California Press, Berkeley, California.

Fisher, S.G.; Gray, L.J.; Grimm, N.B.; Busch, D.E. 1982 . Temporal succession in a desert stream ecosystem following flash flooding. Ecological Monographs 52:93-110.

Fleischner, T.L. 1994. Ecological costs of livestock grazing in western North America. Conservation Biology (8) 3: 629-644.

Graff, W.L. 1988. Fluvial processes in dryland rivers. Springer-Verlag. New York, 346 pp.

Gray, L.J; Fisher, S.G.1981. Postflood Recolonization pathways of macroinvertebrates in a lowland Sonoran Desert stream. American Midland Naturalist 106 (2): 249-257.

Grimm, N.B. 1987. Nitrogen dynamics during succession in a desert stream .Ecology 68: 1157-1170.

Grimm, N.B.; Fisher, S.G. 1989. Stability of periphyton and macroinvertebrates to disturbance by flash floods in a desert stream. Journal of the North American Benthological Society 8: 293-307.

Hastings, J.R. 1959. Vegetation change and arroyo cutting in southeastern Arizona. Journal of the Arizona Academy of Science 1: 60-67.

Lusby, G.G.; Reid, V.H.; Knipe, O.D. 1971. Effects of grazing on the hydrology and biology of the Badger Wash Basin in western Colorado, 1953-1966. Hydrologic effects of land use. Geological Survey Water-Supply Paper 1532-D. United States Government Printing Office, Washington.

Mainguet, M. 1994. Desertification. Natural background and human mismanagement. Second Edition. Springer-Verlag, New York. 314 pp.

Menzel, D.W.; Vacarro, R.F. 1964. The measurement of dissolved and particulate organic carbon in seawater. Limnology and Oceanography 9: 138-142.

Molles, M.C., Jr.; Dahm, C.N. 1990. A perspective on El Niño and La Niña: Global implications for stream ecology. Journal of the North American Benthological Society 9:68-76.

Murphy, J.; Riley, J.P. 1962. A modified single solution method for the determination of phosphate in natural waters. Analytica Chemica Acta 27: 31-36.

Soloranzo, L. 1969. Determination of ammonium in natural waters by the phenylhypochlorite method. Limnology and Oceanography 14: 799-801.

Stream Solute Workshop. 1990. Concepts and methods for assessing solute dynamics in stream ecosystems. Journal of the North American Benthological Society 9:95-119.

Szaro, R.C. 1989. Riparian forests and scrubland community types of Arizona and New Mexico. Desert Plants 9 (3-4): 69-138.

Trotter, E.H. 1990. Woody debris, forest-stream succession, and catchment geomorphology. 9: 141-156.

Vitousek, P.M.; Reiners, W.A. 1975. Ecosystem succession and nutrient retention: an hypothesis. Bioscience 25; 376-381.

Wood, E.D.; Armstrong, F.A.J.; Richards, F.A. 1967. Determination of nitrate in seawater by cadmium-copper reduction to nitrite. Journal of the Marine Biology Association of the United Kingdom. 47: 23-31.

Wagner, F.H. 1978. Livestock grazing and the livestock industry. Pages 121-145 in H.P. Brokaw, editor. Wildlife and American Council on Environmental Quality, Washington D.C.

Geomorphic response of a montane riparian habitat to interactions of ungulates, vegetation, and hydrology

Daniel G. Neary[1] **and Alvin L. Medina**[2]

Abstract.—Wildcat Creek, a tributary of the Black River on the Apache-Sitgreaves National Forest is being studied to determine the impacts of cattle and elk grazing on riparian wet meadows. An intensive survey of a selected stream reach revealed a unique channel development involving an aggradation/degradation process in a pool-riffle sequence of an E-6 stream channel. Grazing and trampling impacts of elk and cattle were found to affect the process in two ways: 1) overgrazing of stream banks resulted in exposure of the soil fabric and loss during high flows, sloughing of banks, channel widening, and a reduction in the ability of plants to trap sediments; and 2) trampling at animal crossings initiated a degradation of riffles by breaking down the armoring gravels which are held in place by native aquatic plants of the genera *Carex*, *Cyperus*, *Juncus*, *Glyceria*, *Scirpus* etc. The importance of the aggradation/degradation process is in the long-term maintenance of montane cienegas in a quasi-stable condition with fully functional processes.

INTRODUCTION

Riparian ecosystems of the American Southwest are valued for their intrinsic characteristics and resources. Unfortunately, most of these ecosystems are in relatively poor condition owing to a combination of natural and man-induced disturbances (DeBano and Schmidt 1989). Considerable research is being conducted to determine how these systems function under different climatic regimes, landforms and land uses. In the arid Southwest, water quantity and quality are very important factors affecting regional economics related to growth and human welfare. Montane cienegas on the Mogollon Rim and in the White Mountains have been highly valued and intensively used for livestock grazing.

One of three watersheds at the head of the Black River in the White Mountains of Arizona, Wildcat Creek, was selected for intensive examination of relationships among hydrology, geomorphology, and vegetation. This is an area in which little information is available for resource managers and scientists, despite many geomorphic and hydrological studies. Interest in this subject was stimulated from efforts to understand how these stream systems function and maintain their unique characteristics. It became clear from field observations that a physical process of scour and deposit was responsible for a unique pool geometry as well as a longer term process - that of building complex channel systems and the aggradation of low-gradient valleys as a whole. Under the impact of livestock and native ungulate grazing starting in the late 1800's and with the decline of specific aquatic plant types, such as *Carex* species, stream systems initiated a process of degradation and downcutting of the stream channel. Herein, we describe the processes observed and make recommendations as to the value of aquatic plants in the formation and maintenance of these ecosystems.

[1] *Project Leader, Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.*

[2] *Research Ecologist, Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona.*

METHODS

Study area

Wildcat Creek is located in the east-central portion of Arizona known as the White Mountains. It is a headwaters stream of the West Fork of the Black River, a tributary of the Salt River. The geology is dominated by unglaciated basalts and andesite. Mean annual rainfall is about 74 cm with 2° C mean air temperature at an average elevation of 2556 m. The vegetation of the riparian meadows is dominated by a number of species of graminoids from the genera *Carex*, *Cyperus*, *Juncus*, *Glyceria*, *Scirpus*, *Agropyron*, and *Poa*. Uplands are dominated by *Pinus ponderosa* on drier southerly slopes on Typic Eutroboralfs soils and mixed-conifer species on northern, wetter exposures on Eutric Glossoboralfs soils (Hendricks 1985).. Soils of these meadows are Typic Argiaquolls found in mesic reaches, Argiaquic Cryoborolls and Argic Cryaquolls in the wetter reaches (Laing et al. 1989). They are alluvial and are saturated about 3-6 months of the year, primarily during the summer monsoons (July-September) and winter (January-March). Elk populations in the area are dense, and in combination with cattle grazing, affect the riparian vegetation and stream morphology.

Surveys

The Wildcat Creek drainage consists of steep upper and lower sections with a low gradient middle reach which contains a relatively narrow montane meadow. A planimetric survey of a 900 m portion of the mid-section of Wildcat Creek was conducted using a laser level. Longitudinal and valley profile measurements were taken to portray channel configurations. Additional measurements taken to characterize stream and channel geometry included: channel width, water depth, bank undercut dimensions, pool and riffle length, stream gradient, number and location of old channels, and streamside vegetation composition and cover. Data were analyzed to produce graphical depictions of site conditions. Photographs were taken to illustrate specific aspects of how vegetation influences streambank morphology. The soils of the site were examined and identified.

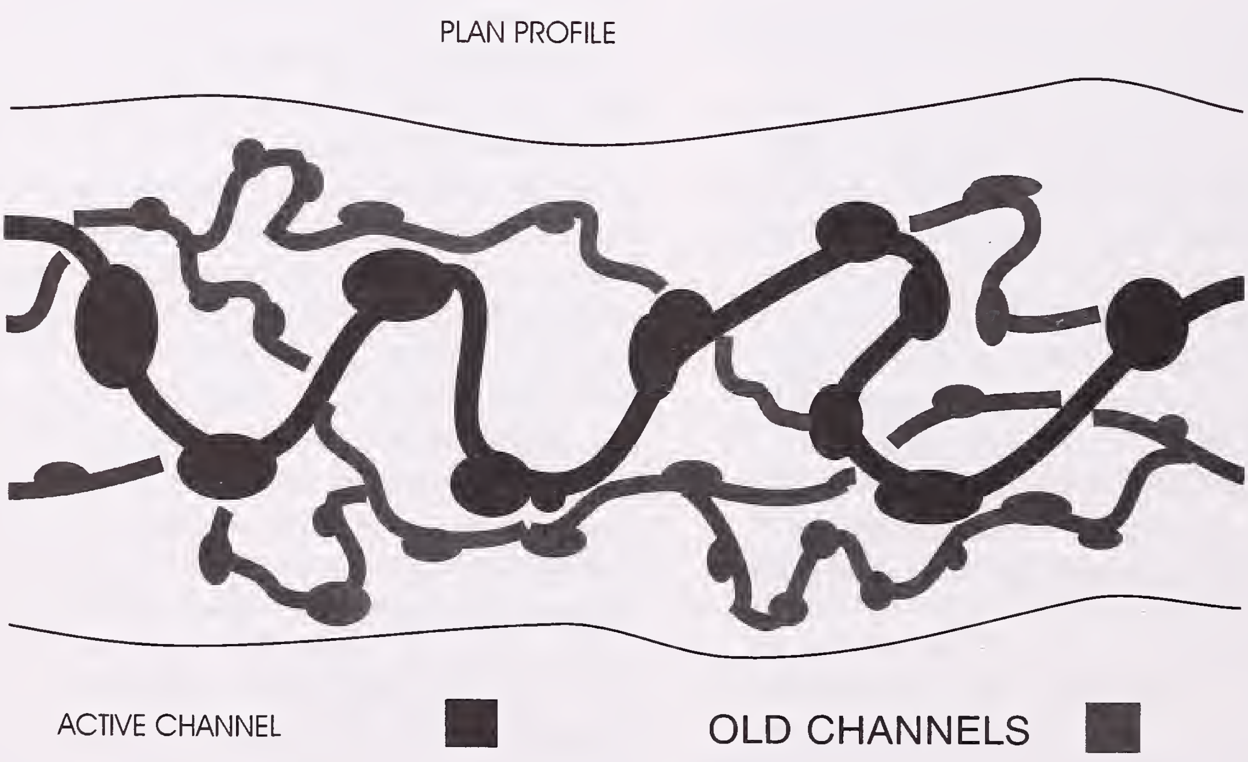


Figure 1. Plan profile of the active and old channels in the Wildcat Creek riparian meadow, Apache-Sitgreaves National Forest.

RESULTS

Geomorphic, vegetation, soils, and animal influence data are still being collected. This paper discusses some of the preliminary results.

Geomorphology

The soils of wet meadows are a product of the cumulative interactions of hydrological (scour and deposit) effects upon the stream channel and the floodplain, as well as the biological effects of vegetation and animals. These interactions can also manifest themselves to produce other soil types (Argiaquolls) typical of mesic conditions such as old meadows that have had the water table lowered as described above.

Valley dimensions in the study section ranged from 48 to 160 m wide. The stream channel was classified as an E-6 type (Rosgen 1994) with such characteristics as: 1.5% slope, sinuosity of 2.1, entrenchment ratio of 2.6, and width depth ratio of 9.6. Old channels are common (4-5) in wider reaches with at least 2 in the narrow sections (Figure 1).

A longitudinal profile survey was conducted to determine the geometry of pools and riffles. The average pool is 5.85 m long, with a minimum width of 86 cm and maximum width of 177 cm, a minimum pool depth of 19 cm and a maximum depth of 50 cm. Scour sections occur downstream of all riffle sections, and gravel deposits form on the inter-pool riffles (Figure 2). The scours occur mainly during snowmelt runoff high flows, but summer monsoon flows can occasionally reach scour velocities. Over time these two major physical processes interact with aquatic vegetation components to result in the aggradation of alluvial materials in these meadows. Five distinct geomorphic actions occur as a result of the aggradation. Scouring action results in upstream migration (1), and deepening of pools (2). The deposited material in combination with the vegetation causes riffle areas to aggrade (3) in three dimensions: longitudinal, horizontal and vertical. The aggradation process results in a deepening of the pool by elevation of the water surface (4), and a change in channel direction during peak flows to other older channels of lower elevation (5). This process is repeated in the new active channel. However, a change in the long term aggradation process can be reversed through the interaction of another biological component - animals.

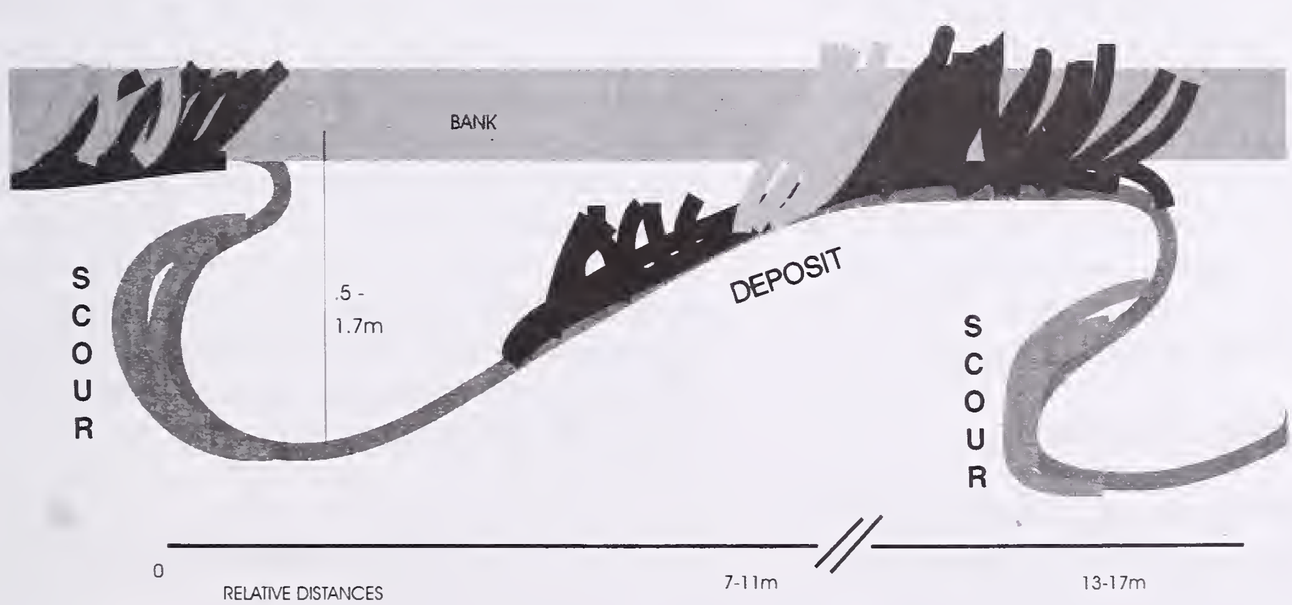


Figure 2. Longitudinal view of typical scour and deposit zones of pool-riffle sequences in the Wildcat Creek riparian meadow, Apache-Sitgreaves National Forest.

Vegetation influences

The type of vegetation is most important in determining the direction and extent of channel aggradation or degradation. Native aquatic graminoids genera such as such as *Carex.*, *Cyperus.*, *Glyceria*, *Juncus*, and *Scirpus* are essential in maintaining stream bank integrity and capturing sediments (Medina 1996). Deposited material is quickly colonized by *Carex nebraskensis*, *C. lanuginosa*, and other sedges. The strong, fibrous, rhizomatous roots of these species keep the substrates intact, while foliar parts trap additional materials, thereby accelerating the aggradation process (Figure 2). Roots of native aquatic plant species are fibrous, thick (5-10 mm) and grow to depths of 1.0-1.5 m. Those of introduced graminoids such as Kentucky bluegrass (*Poa pratensis*), wheat grasses (*Agropyron* spp.), or orchard grass (*Dactylis glomerata*) are shallow (<20 cm) and fragile (diameters <2 mm). The trapping and armoring of the deposited substrates by native vegetation results in elevated, constricted riffles. These riffles are subsequently colonized by *Juncus* species in shallower sections, and species of *Glyceria* and *Scirpus* in deeper water. Bank heights are reduced as a result of the ponding action.

Eventually, riffle areas of lower pools aggraded to such an extent (without being able to change channels) that they inundated the immediate upstream riffle and combined with the upper pool, thereby forming one long still water area. The depositional rate in the inundated riffle is apt to increase because of the reduced stream gradient.

The continual aggradation of riffles results in subsequent changes in channel direction to an older channel of lower elevation. This channel will develop similar scour and fill morphology with time. Eventually riffles in this channel will also cause another change in channel direction.

Animal influences

Ungulates can disrupt the aggradation process through the cumulative effects of herbivory and the tearing of the vegetation fabric with their hooves. When foliar parts are reduced, so is their capacity to trap and settle out suspended sediments which would otherwise get incorporated in the riffle. Hooves tear at the roots of the plant and initiate a weakening of the soil fabric along the streambank, which leads to removal of fines by the current, and eventually initiates a down cutting of the riffle.

Deterioration of the stream bank accelerates with continued ungulate use until large portions of streambank materials are sloughed into the channel. The lateral direction in which the channel is apt to change is partly a function of the type of plant that inhabits the streambank. Streambanks with such fine rooted vegetation as Kentucky bluegrass (*Poa pratensis*) are much more susceptible to erosion than banks with native species of *Carex* (Medina 1996). Left unchecked, eventually the downcutting of the channel will result in:

1. Complete removal of riffle areas,
2. A longer but shallower pool,
3. Lowering of the water table, and
4. Changes in streambank vegetation composition from aquatic to more mesic species.

SUMMARY AND CONCLUSION

The stream channel aggradation process produced by the interaction of native aquatic graminoids such as *Carex*, *Cyperus*, *Glyceria*, *Juncus*, and *Scirpus* with bedload substrates is important to the long-term stability of montane cienegas. Hoof action of both native (elk) and introduced ungulates (cattle) can initiate breakdown of channel substrates and banks, leading to degradation of the riparian systems. Introduced mesic graminoids such as *Poa*, *Agropyron*, and *Dactylis* are not able to contribute to the riparian system channel aggradation and are much less able to withstand the impact of ungulates due to the nature of their root systems. Understanding of the aggradation/ degradation processes is a prerequisite to successful management of these riparian systems for animal forage and fish habitat.

LITERATURE CITED

DeBano, L.F. and L.J. Schmidt. 1989. Improving southwestern riparian areas through watershed management. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station,

General Technical Report RM-182, Fort Collins, CO, 33 p.

Hendricks, D.M. 1985. Arizona Soils. University of Arizona Press, Tucson, AZ, 244 p.

Laing, L., N. Ambos, T. Subirge, C. McDonald, C. Nelson, and W. Robbie. 1989. Terrestrial ecosystem survey of the Apache-Sitgreaves National Forest. USDA Forest Service, Region 3, 453 pp.

Medina, A.L. 1996. Native aquatic plants and ecological condition of Southwestern wetlands and riparian areas In USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report, Fort Collins, CO, this issue.

Rosgen, D.L. 1994. A classification of natural rivers. Catena 22:169-199.

Willow establishment in relation to cattle grazing on an eastern Oregon stream

Nancy L. Shaw[1] and Warren P. Clary[2]

Abstract.—Natural regeneration and growth of coyote willow (*Salix exigua* Nutt. ssp. *exigua*) and whiplash willow (*S. lasiandra* Bemth. var. *caudata* [Nutt.] Sudw.) were monitored from 1987 to 1993 on a low-elevation eastern Oregon stream degraded by more than a century of heavy livestock grazing. Treatments were no grazing, moderate spring grazing, moderate fall grazing, and continued heavy, season-long grazing by cattle. Fresh sediments deposited by a May 1987 flood provided moist, open seedbed conditions for willow recruitment from off-site seed sources. Initial establishment of coyote willow was limited, but density increased through 1990 with some fluctuation thereafter. Over the 7-year period, density was greatest in pastures grazed moderately in spring and least in pastures grazed moderately in fall or heavily season long. By contrast, large numbers of whiplash willows established in 1987, but densities declined through 1990 and remained stable thereafter. Densities were greater in ungrazed or moderately grazed pastures compared to those grazed season long. Height of both willow species generally increased over time in all pastures and was greater in ungrazed and moderately grazed pastures compared to those grazed season long. Browsing by deer each summer substantially reduced willow growth in all pastures, possibly masking treatment differences. Few willows have grown beyond browsing height to increase site stability and begin providing on-site seed sources.

INTRODUCTION

Alteration of low-elevation streams of the sagebrush (*Artemisia* spp.) steppe by human activities, particularly livestock grazing, has resulted in the loss of willows (*Salix* spp.) and other riparian vegetation, reduced bank stability, increased soil erosion, and lowering of the water table (Kaufmann and Krueger 1984; Thomas et al. 1979). As a result, stream channels become wider and more unstable and streamside vegetation is replaced by more mesic or xeric species, including introduced weeds (Swanson 1988). The negative effects of stream degradation on watershed stability, water quality, wildlife habitat, and human recreational, aesthetic, and economic uses have been extensively documented (Chaney et al. 1990; Platts 1982; US-GAO 1988).

Recovery of lost or depleted willow populations is dependent upon the availability of seeds or vegetative material (detached twigs and branches, resprouting trees), microsite conditions favorable for germination or rooting and establishment, and grazing management practices that prevent excessive browsing of young seedlings and resprouting trees (Kovalchik and Elmore 1992). A better understanding of requirements for establishment and stand development of individual willow species as well as their response to grazing practices would aid in devising appropriate management schemes for hastening recovery of degraded riparian areas.

[1] Botanist, USDA Forest Service, Intermountain Research Station, located at Boise, ID. Headquarters is in Ogden, UT.

[2] Project Leader, USDA Forest Service, Intermountain Research Station, located at Boise, ID. Headquarters is in Ogden, UT.

Coyote willow (*Salix exigua* Nutt. ssp. *exigua*)and whiplash willow (*Salix lasiandra* Benth. var. *caudata* [Nutt.] Sudw.) are two early seral willow species common to riparian areas of the sagebrush steppe. Both willows rapidly colonize recent alluvial deposits. Their roots and shoots stabilize streambanks and dissipate flood energy. Stands persist on frequently flooded sites, but may be shaded out by later seral species on stabilized sites. Coyote willow is a short-lived, normally shrubby species that forms dense clonal thickets by development of shoots from buds on lateral roots (Argus 1973). It is highly tolerant of flooding and may occur below the high water line (Brunsfeld and Johnson 1985). Whiplash willow ranges in growth habit from multistemmed shrubs to tree-like forms. It resprouts following crown removal, but does not spread by suckering (Argus 1973; Haeussler and Coates 1986; Zasada 1986). The objective of this study was to measure establishment and development of coyote willow and whiplash willow in response to season and intensity of cattle grazing on an unstable stream in the sagebrush steppe of eastern Oregon. The study was conducted in cooperation with the USDI-Bureau of Land Management, Vale District, local permittees, and landowners.

METHODS

Study site

The study site (44°15'N 117°35'W, elevation 880 to 975 m) is located on Pole Creek (Poall Creek) in the eastern foothills of the Cottonwood Mountains, Malheur County, Oregon. Climate is semiarid. Annual temperature at Vale, Oregon, the nearest reporting station, is 10°C; ranging from -3°C in January to 23°C in July. Annual precipitation is 244 mm with 61 percent falling from October through March (USDC-NOAA 1986-1993). Soils are derived from basalt and rhyolite, ranging from shallow and rocky on ridges to deep alluvial deposits in former wet meadows and sandy to gravelly deposits along stream channels. Uplands are steep (25 to 45 percent slopes) and support a Wyoming big sagebrush/cheatgrass (*Artemisia tridentata* Nutt. var. *wyomingensis* [Beetle & A. Young] S. L. Welsh/ *Bromus tectorum* L.) biotic climax. A stiff sagebrush/Sandberg bluegrass (*Artemisia rigida* [Nutt.] Gray/*Poa secunda* Presl) habitat type is restricted to rocky, basalt sites with shallow soils. Season of use for the Poall Creek grazing allotment is April 1 to September 30 in even years and July 1 to October 31 in odd years (USDI-BLM 1982, 1987).

Pole Creek is spring-fed and perennial with a 2.5 to 3 percent gradient and a uniform flow of about 0.03 $m^3 s^{-1}$. Loss of native bank-stabilizing riparian vegetation as a result of livestock grazing practices has resulted in downcutting, in some cases to bedrock. Incised banks 1 to 3 m or more in height border a narrow floodplain, generally ranging from about 10 to 30 m in width. Unstable sandbars are initially colonized by species of horsetail (*Equisetum* spp.) and speedwell (*Veronica* spp.). Sediments on low banks and terraces support Kentucky bluegrass (*Poa pratensis* L.) and creeping bentgrass (*Agrostis stolonifera* L.) communities. Drier benches supporting exotic weeds grade into the sagebrush community. A limited description of the area provided by Peck (1911) and remnant plants, logs, and seedlings suggest woody riparian communities present pregrazing may have included coyote willow, whiplash willow, narrow-leaved cottonwood (*Populus angustifolia* James), and black cottonwood (*Populus trichocarpa* T. & G.). Remnant shrubs associated with the riparian area include blueberry elder (*Sambucus cerulea* Raf.), Wood's rose (*Rosa woodsii* Lindl.), and common chokecherry (*Prunus virginiana* L.).

Grazing treatments and willow recruitment and growth

Eight pastures ranging from 3.7 to 8.9 ha in size were installed along a 5-km segment of Pole Creek in 1987. Five grazing treatments were applied from 1987-1993 in a completely randomized design with two replications. Four of these treatments are discussed here: season-long grazing, heavy to very heavy use; spring grazing, light-to-moderate use; fall grazing, light-to-moderate use; and protection from grazing (ungrazed pastures). All pastures except those grazed season long were fenced to exclude livestock, but not big game. Pastures grazed season long were located approximately 0.5 km from the nearest fenced pastures to avoid a water gap concentration effect in their use and were grazed with the remainder of the allotment. Spring

(early May) and fall (early October) grazing treatments were normally applied by releasing 4 cow/calf pairs into each pasture for about 10 days. Treatment duration was determined by monitoring forage utilization by weight at streamside, primarily in Kentucky bluegrass and creeping bentgrass communities. Over the period of study, cattle use was 70 percent in pastures grazed season long, 21 percent in spring-grazed pastures, 42 percent in fall-grazed pastures, and 8 percent in protected pastures (Clary and Shaw 1994).

Willow recruitment and growth were evaluated annually in early October 1987-93. In each pasture, twenty 5-m wide belt transects were placed perpendicular to the stream, spanning the corridor of stream-affected vegetation. Species, height, number of basal stems, distance from water, understory vegetation, substrate, and use by livestock or wildlife were determined for each willow occurring within the transects. Transect length and width of active and slack water were also recorded. Precipitation was measured at Brogan, OR, 3 km southeast of the study site.

Statistical analysis

For each willow species, plant density and growth data were compared among treatments and years using a two-way, repeated-measures analysis of variance. A two-way analysis of variance was used to compare basal stem numbers and distance from water among treatments and between species for 1993 data. Fisher's Least Significant Difference was used to separate means where appropriate. All differences reported are significant at $P<0.10$. Standard errors are provided as a measure of variability ($\bar{x}$[se]) around means presented in the text.

RESULTS

Dry conditions prevailed during 1987 to 88 and 1990 to 92 with Brogan precipitation ranging from 165 to 201 mm (fig. 1). Greater precipitation fell in 1989 and 1993. Although spring runoff did not produce major flooding during the study period, high-intensity, short-duration storms occurred in May 1987, 1989, and 1991 and August 1987 and 1990.

Prior to initiation of the study, no mature, seed-producing willows were found within the study area. Willows present consisted almost entirely of small, heavily-browsed plants. Scattered seed-producing willows were noted downstream with the nearest plant, a whiplash willow, about 0.5 km below the lowest pasture. Additional sources may be available in the head of the watershed, several kilometers above the pastures. A few willows within the pastures began producing seed by 1990.

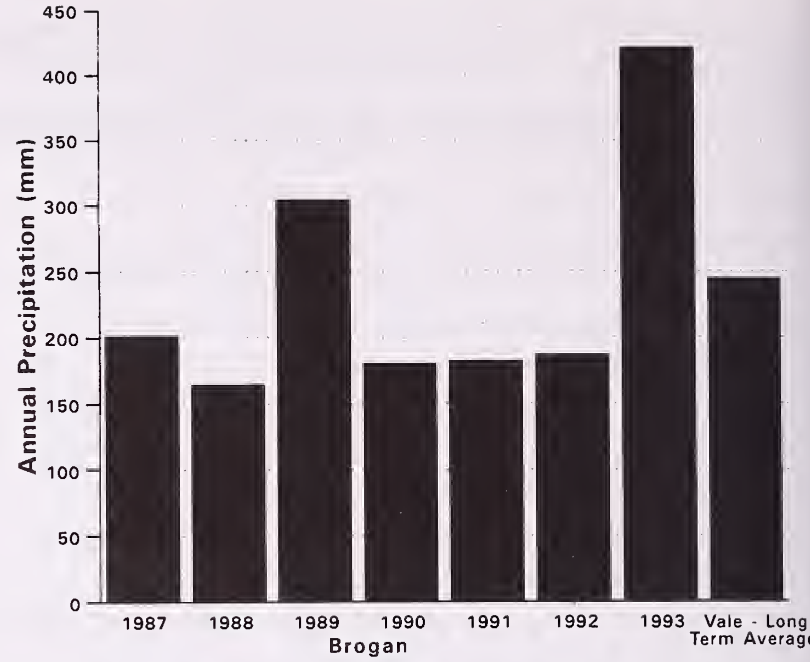


Figure 1. Annual precipitation 1987-1993, Brogan, OR and long-term precipitation, Vale, OR.

Throughout the study, willow seedlings occurred almost exclusively on saturated sediment surfaces free of vegetative competition, sediments supporting horsetail and speedwell species, and in slack water. Scattered willows were observed along dry channels or in Kentucky bluegrass communities. In October 1993, about 95 percent of all willows were less than 1.6 m from active water.

Willow density fluctuated over time with contrasting trends developing for the two species (fig. 2). Though establishment of coyote willow seedlings was limited in 1987, their density increased through 1989 and generally remained stable through 1993. Over the 7-year period, density in spring-grazed pastures exceeded that in fall-grazed pastures or in pastures grazed season long. By contrast, large numbers of whiplash willow seedlings emerged in 1987, possibly due to a combination of seed availability and the presence of extensive fresh sediment surfaces deposited following a high-intensity rain storm in May, just prior to seed dispersal. Density of whiplash willow

generally declined through 1990, remaining stable thereafter. Ungrazed and moderately grazed pastures supported greater seedling densities than pastures grazed season long.

Height of both willow species has gradually increased over time, with the greatest increase occurring in 1993, an unusually wet year (fig. 2). The increase occurred even though all pastures, even those not grazed by cattle, receive heavy browsing by mule deer (*Odocoileus hemionus* Rafinesque). Over the 7-year period, seedling height was greater in ungrazed or moderately grazed pastures compared to pastures grazed season long. In 1993, number of basal stems per plant was 3.4(0.2) with no differences among treatments or between species.

DISCUSSION AND CONCLUSIONS

Trends in willow recruitment and establishment were complicated by factors uch as natural variability within and among pastures, effects of periodic high-intensity rainstorms, seed availability, and use by deer in all pastures. Seed germination and establishment of willows depend on a series of stochastic events. Seeds are dispersed by wind and water and remain viable for only a short period; thus only those that are quickly dispersed to suitable microsites will germinate. Saturated sediment deposits left by flooding provide the light and moisture conditions required for germination and emergence of coyote and whiplash willow. Although flooding resulting from high-

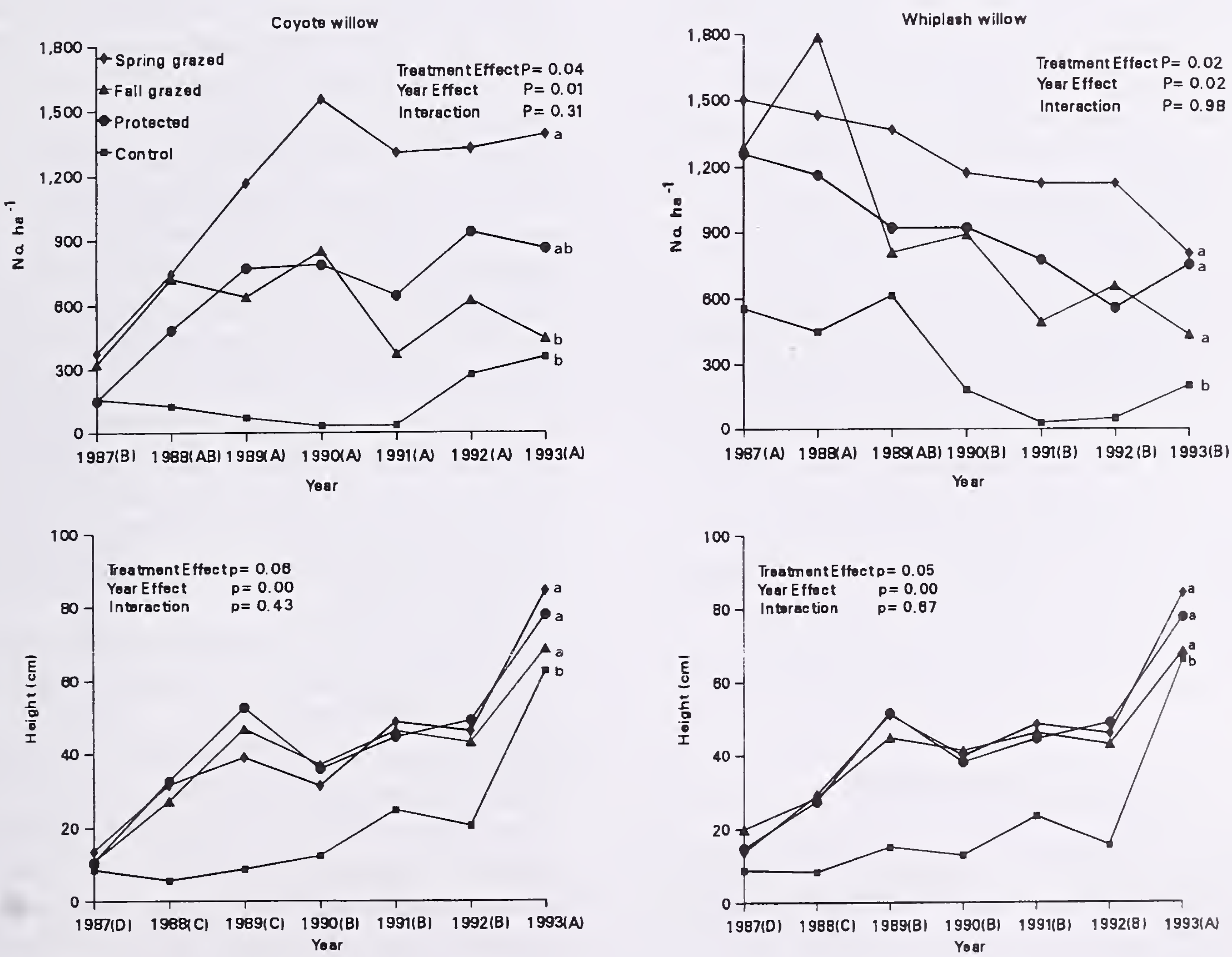


Figure 2. Density and height of coyote willow and whiplash willow in 1987-1993 for cattle grazing treatments at Pole Creek. Years followed by the same uppercase letter do not differ (P≥0.10). Treatment lines followed by the same lowercase letter do not differ (P≥0.10).

intensity summer storms during this study may have provided sediments for willow germination, small seedlings were also buried or uprooted by such events.

Cattle use in grazed pastures and browsing by deer in all pastures has severely restricted willow establishment and growth. Kovalchik and Elmore (1992) reported that first-year willow seedlings are sensitive to cattle grazing and often killed as a result of uprooting or trampling. The rapid increase in height noted for all pastures in 1993 was likely related to good growing conditions occurring throughout the cool, moist summer and possibly a dilution of browsing pressure in the riparian area by favorable forage conditions elsewhere. By 1993, however, only 9(2.4) percent of all willows exceeded 1.5 m in height. Crowns of plants reaching this height are not easily browsed and develop rapidly. Ability of willows to grow out of reach of browsers is essential for recovery. Healthy willows can achieve shoot and root sizes and densities needed to trap sediments and improve stream stability. The trapped sediments, in turn, provide suitable microsites for other riparian vegetation.

Reduced cattle grazing or protection from grazing over a larger portion of the Pole Creek watershed might permit recovery of riparian vegetation to begin over a larger area, diluting deer browsing pressure to the point that willow seedlings could become established and grow beyond the reach of wildlife and livestock (Briggs et al. 1994). Due to the preponderance of exotic herbaceous species along the stream, recovery of native grasses, grasslike species, and forbs could be extremely slow. Spot plantings of native herbaceous species and more extensive plantings of shrubs associated with riparian areas may be necessary to speed the recovery of native species.

LITERATURE CITED

Argus, George W. 1973. The genus *Salix* in Alaska and the Yukon. Pub. Botany 2. Ottawa, Ontario: National Museums of Canada, National Museum of Natural Sciences. 279.

Briggs, Mark K.; Roundy, Bruce A.; Shaw, William W. 1994. Trial and error: assessing the effectiveness of riparian revegetation in Arizona. Restoration & Management Notes. 12(2): 160-167.

Brunsfeld, Steven J.; Johnson, Frederic D. 1985. Field guide to the willows of east-central Idaho. Bull. 39. Moscow, ID: University of Idaho. 95.

Chaney, Ed W.; Elmore, Wayne; Platts, William S. 1990. Livestock grazing on western riparian areas. Produced for the U.S Environmental Protection Agency by the Northwest Resource Information Center, Inc. Eagle, ID. Denver, CO: U.S. Environmental Protection Agency. 45.

Clary, Warren P.; Shaw, Nancy L. 1994. Response to grazing control by an unstable riparian system. In: Northwest regional riparian symposia: Diverse values: seeking common ground; 8-9 December 1994; Boise, ID. Moscow, ID: University of Idaho, Idaho Water Resources Research Institute, Idaho Riparian Cooperative: 96-101.

Haeussler, S.; Coates, D. 1986. Autecological characteristics of selected species that compete with conifers in British Columbia: a literature review. Victoria, B.C.: Canadian Ministry of Forests, Information Services Branch. 180.

Kaufmann, J. Boone; Krueger, W. C. 1984. Livestock impacts on riparian ecosystems and streamside management implications. a review. Journal of Range Management. 37(5): 430-438.

Kovalchik, Bernard L.; Elmore, Wayne. 1992. Effects of cattle grazing systems on willow-dominated plant associations in central Oregon. In: Clary, Warren P.; McArthur, E. Durant; Bedunah, Don; Wambolt, Carl L., compilers. Proceedings—symposium on ecology and management of riparian shrub communities; 1991 May 29-31; Sun Valley, ID. Gen. Tech. Rep. INT-289. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station: 111-119.

Peck, Morton E. 1911. Summer birds of Willow Creek Valley, Malheur County, Oregon. The Condor. 13(2): 63-69.

Platts, William S. 1982. Livestock and riparian fishery interactions. What are the facts? Transactions of the 47th North American Wildlife and Natural Resources Conference. 47: 507-515.

Swanson, Sherman. 1988. Using stream classification to prioritize riparian rehabilitation after extreme events. In: Abell, Dana L., tech. coord. Proceedings of the California riparian systems conference: protection, management, and restoration for the 1990's; 1988 September 22-24; Davis, CA. Gen. Tech. Rep. PSW-110. Berkeley,

CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station: 96-101.
Thomas, Jack W.; Maser, Chris; Rodiek, Jon E. 1979. Wildlife habitats in managed rangelands - the Great Basin of southeastern Oregon. Riparian Zones. Gen. Tech. Rep. PNW-80. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Forest and Range Experiment Station. 18.
United States Department of Commerce, National Oceanic and Atmospheric Administration. 1986-1993. Climatological data Oregon. Vols. 92-99. U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Climatic Data Center. n.p.
United States General Accounting Office. 1988. Public rangelands: some riparian areas restored but widespread improvement will be slow. GAO/RCED-88-105. Gaithersburg, MD: U.S. General Accounting Office. 85.
United States Department of the Interior, Bureau of Land Management, Vale District. 1982. Poall Creek Allotment Management Plan 0103. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Forestry Sciences Laboratory, Boise, ID. n.p.
United States Department of the Interior, Bureau of Land Management, Vale District. 1987. Poall Creek Allotment Evaluation. Unpublished paper on file at: U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Forestry Sciences Laboratory, Boise, ID. 3 p.
Zasada, John. 1986. Natural regeneration of trees and tall shrubs on forest sites in interior Alaska. In: Van Cleve, K.; Chapin, F. Stuart III; Flanagan, P. W.; [and others], eds. Forest ecosystems in the Alaska taiga: a synthesis of structure and function. N.Y.: Springer-Verlag: 43-73.

Insects of the riparian

Terrence J. Rogers[1]

Abstract.—This paper describes life histories, defoliation problems and other activities of insects associated with forest tree species growing along high elevation streams and river banks. In addition, examples of insects and diseases associated with lower elevation riparian areas are given.

Although the title of this presentation is "Insects of the Riparian," it might be more aptly entitled "Insects of High elevation Watersheds, Streams and River Banks." As an entomologist with the USDA Forest Service, I provide technical assistance to Federal land managers on insects and diseases. We do not work on state and private lands, but we do work with state counterparts on occasion. Most of the work I do has been in the spruce-fir, mixed conifer, ponderosa pine, and pinyon pine forest cover types. In the higher elevation spruce-fir and middle elevation mixed conifer forest cover types, spruce, true firs, Douglas-fir, and ponderosa pines grow along the streams and river banks. Insect outbreaks associated with these tree species usually affects the entire watershed where these streams and river banks occur. Therefore, I am not going to talk about aquatics such as mayflies, dragonflies, stone flies, etc., but rather about forest insects associated with forest tree species growing along high elevation streams and river banks. Later, however, I will give examples of insects and disease associated with the lower elevation riparian areas.

All of the insects and diseases discussed are native to the Southwest. They have evolved with their hosts for thousands of years. Many of these insects and diseases are host specific. Others feed on a number of host trees. Because of time only few examples of the important insects and diseases will be discussed.

[1] *USDA Forest Service, Southwest Region, Federal Building, Albuquerque, NM.*

Defoliators are insects that feed on the foliage or needles causeing partial or complete foliage or needle loss. The western spruce budworm, *Choristoneura occidentalis*, periodically increases to outbreak levels defoliating large areas of the mixed conifer forest cover type. Areas susceptible to western spruce budworm outbreaks are usually multistoried and very dense. Several outbreak cycles of this insect have occurred in the Southwest in both Arizona and New Mexico. Western spruce budworm larvae feed on the new developing foliage buds and developing needles of spruce, true firs, and Douglas-fir. Defoliated trees usually have a reddish appearance as if the trees were singed by fire. Several years of consecutive defoliation cause the affected trees to appear grey with thinning crowns. Suppressed trees are often killed and many of the dominant and codominant trees are topkilled. These defoliated trees are highly susceptible to bark beetle attack. Outbreaks of the western spruce budworm have occurred on the Carson, Santa Fe, Cibola, Lincoln and Gila National Forests and well as other Federal and adjacent private ownerships. Periodic outbreaks of this insect have also occurred throughout the mixed conifer forest cover types in Arizona.

The Douglas-fir tussock moth, *Orgyia pseudotsugata* is also an important defoliator of ornamental and forest Douglas-fir, white fir, and blue spruce. Needles in the upper portion of infested trees may be completely removed after one or two years of feeding. In Southwestern forests, tussock moth outbreaks have generally been confined to mature and over mature multistoried stands of spruce, white fir and

Douglas-fir bordering riparian areas. Heavily defoliated trees may result in water temperature increases and erosion. The eggs of the tussock moth hatch in late May and early June. The caterpillars feed on the new and old foliage. Tussock moth larvae are covered with long, thin body hairs that develop into tufts. Some people develop an itchy rash from exposure to the frequently airborne caterpillar hairs. Because the female moth is wingless, the primary means of dispersal from tree to tree is by windblown larvae. Young larvae congregate on the tops of defoliated trees and drop on silken threads. These threads eventually break and give a ballooning effect to the larvae. If caught by a strong wind, some larvae may be blown great distances. Many larvae will never find a suitable host and will perish during dispersal.

Trees heavily defoliated by the western spruce budworm and tussock moth are often susceptible to attack by bark beetles belonging to the genus *Dendroctonus*. These bark beetles frequently attack and kill mature and over mature trees as well as suppressed trees along riparian areas. Because *Dendroctonus* beetles are host specific, they can be easily identified by the trees they attack and kill. For example, the spruce beetle, *Dendroctonus rufipennis*, attacks and kills spruce, the Douglas-fir beetle, *Dendroctonus pseudotsuga*, attacks and kills Douglas-fir, and the fir engraver beetle, *Scolytus ventralis*, attacks and kills white fir. Ponderosa pine, also a component of riparian areas in the mixed conifer forest cover type, is often attacked and killed by one or a combination of mountain pine beetle, *Dendroctonus ponderosae*, western pine beetle, *Dendroctonus brevicomis*, and roundheaded pine beetle, *Dendroctonus adjunctus*. Each of these bark beetles can be readily identified by the egg galleries they make as they bore under the bark. Symptoms of bark beetle attack include boring dust in the cracks and crevices of the bark, pitch tubes (globules of resin) on the trunk of the tree, and foliage changing from green to yellow or red. Woodpecker activity on the trunk is also a good indication that the tree has been attacked.

In 1995, an outbreak of the alder flea beetle, *Altica ambiens* ocurred at several areas along the Hassayampa River on the Prescott National Forest, Arizona. This insect usually occurs at low population levels, but occasionally outbreaks occur. The alder flea beetle is a native insect belonging to the insect family Chrysomelidae and occurs throughout the western United States. These insects are referred to as flea beetles because they are powerful jumpers. Alder is the principal host. Both the adults and larvae feed on the alder foliage often causing light to heavy defoliation to to host trees. During the early 1970's, alder flea beetle defoliation was also detected along the Gila River in New Mexico. The adults chew holes in the leaves while the larvae are skeletonizers feeding on the tissues between the leaf veins. The shiny dark blue adults hibernate during the winter in the debris beneath the trees and in other sheltered places. They then reappear in the spring to resume feeding. Outbreaks of this insect appear to be short lived and damages to the infested trees are usually minor.

Numerous insects and diseases also affect the cottonwood and elms and other vegetation growing in the riparian areas along the Rio Grande. At this time of year (fall), for example, the fall web worm, *Hyphantria cunea* can be seen forming webs and feeding in colonies on the cottonwoods along the Rio Grande. Although the webs formed by these insect defoliators are conspicuous and unsightly, web worm feeding activity generally result in little damage to the infested trees. Early in the spring, many of the cottonwood leaves are infested with tiny leaf miners, possibly belonging to the family of true flies (Order Diptera) called Agromyzidae. These insects are a natural component of the riparian ecosystem where cottonwoods reside and generally cause little if any significant damages to the trees they feed on. Siberians elms are also becoming established in the bosque. These trees are susceptible to elm leaf beetle defoliation. Last year (1994) cottonwood leaf beetle adults were observed at high levels near the bosque, however, no defoliation was reported.

Diseases are also a natural part of the riparian ecosystem. Cottonwoods along the bosque near San Antonio, New Mexico are heavily infected with true mistletoe. This disease is an obligate parasite which causes severe branch dieback. This disease is transmitted by birds passing the seeds through their feces. Trees heavily infected with this disease indicate they were used as roosting trees. Cottonwoods are also susceptible to cytospora canker. This disease causes branch dieback on large trees and morality to infected seedlings and saplings.

Alders are susceptible to hypoxylon and cytospera cankers. These diseases can cause branch dieback and/or tree mortality to stressed trees.

Willows are often infected with rusts. Leaves infected with rust prematurely turn yellow-gold in late August, die, and are shed in early September.

One last comment about the bosque. All of the insects and disease discussed are native. These insects have a complex of predators and parasites that keep potential native pest insects in check. Introduced pests, however, can pose a problem. For example, the gypsy moth, a non-native insect, if introduced into New Mexico, could be a serious threat to hardwoods of the Bosque since they have no native predators or parasites to keep them in check.

Distribution of Rio Grande Cutthroat Trout and its co-occurrence with the Rio Grande Sucker and Rio Grande Chub on the Carson and Santa Fe National Forests

Bob Calamusso[1] **and John N. Rinne**[2]

Abstract.—Studies were initiated in June, 1994 by the USDA Forest Service, Rocky Mountain Forest and Range Experiment Station to update knowledge on the distribution of the Rio Grande cutthroat trout, a Forest Service Sensitive Species, and its co-occurrence with two native cypriniforms, Rio Grande sucker and Rio Grande Chub. The Rio Grande sucker is listed as endangered by the state of Colorado. The native cutthroat was found to co-occur with the native sucker in Tusas Creek on the Carson National Forest, and in the Rio de las Vacas, American Cr. and the Rito de las Palomas on the Santa Fe National Forest. By comparison, the native trout co-occurred with the chub in Canjilon Cr., El Rito Cr., Rio San Antonio, and Nutrias Cr. on the Carson National Forest. The three native species co-occurred in the Rio de las Vacas, Clear Creek, American Creek, and Rito de las Palomas on the Santa Fe National Forest. Seven new localities (Canada de Osha, Comales Cr., Agua Piedras, Rio de las Trampas, Rio San Leanardo, Italianos Cr. and Yerba Creek) were added to the distributional records of the native cutthroat—all on the Carson National Forest. Two new localities were added to the know distribution of the native sucker (Polvedera Cr. and Canones Cr.).

INTRODUCTION

The status and distribution of the Rio Grande cutthroat trout, *Oncorhynchus clarki virginalis*, has been an objective of research among professional fishery managers for several decades. The first specimens of Rio Grande cutthroat trout were collected from Ute Creek, Costilla County, Colorado in 1853 near the site of Fort Massachusetts, by the Pacific Railroad expedition. The specimens were described by Girard (1856) as *Salar virginalis*. Collections of Rio Grande cutthroat trout were also taken from the Fort Garland area, which was approximately 7.2 km south of Fort Massachusetts. The Rio Grande cutthroat trout is presently classified as a subspecies of *Oncorhynchus clarki* instead of as a distinct species.

The original distribution of the Rio Grande cutthroat trout is unknown (Wernsman, 1973, Wallace and Behnke, 1974). Cope (1886) described a "black-spotted" trout with "basihyal" teeth from southern Chihuahua. The location of this collection

[1] *Fisheries Biologist, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, located at New Mexico State University, Las Cruces, New Mexico. Headquarters is in Flagstaff, Arizona.*

[2] *Fisheries Research Biologist, USDA Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona. Headquarters is in Fort Collins, Colorado.*

has never been identified and the samples have subsequently been lost, which precludes taxonomic analysis (Propst, 1976). Needham and Gard (1964) described a Pacific Coast trout as *Salmo chrysogaster*; it, however, is not related to the Rio Grande cutthroat trout. Wallace and Behnke (1974) considered the old citations of Rio Grande cutthroat trout occurrence in Texas and old Mexico as dubious.

Behnke (1967) identified cutthroat trout from Indian Creek, a stream located in the Sacramento Mountains, Otero County, New Mexico, as Rio Grande cutthroat trout. These specimens more closely resembled the Pecos variant of *virginalis* than the Rio Grande variant and are believed to have been transplanted from the Pecos River (Propst, 1976). This location is the southern most extension of the known Rio Grande cutthroat trout distribution.

Indigenous occurrence of Rio Grande cutthroat trout in the Canadian River system has been questioned over time. An anonymous author with the appellation "Apache" stated in an 1877 article of Forest and Stream that trout were abundant "at the headwaters of the Vermejo." A fish survey by the New Mexico Department of Game and Fish reported that "native" cutthroat were found in the headwater streams of the Canadian (Propst, 1976). Wallace and Behnke (1974) stated "that the indigenous occurrence of cutthroat trout in the headwaters of the Canadian River basin of New Mexico has never been established, but if trout were native to the Canadian River drainage they would be *S. c. virginalis*, derived from headwater transfer from the Pecos River drainage." Stork (1975) believed that the evidence of Rio Grande cutthroat trout being indigenous to the Canadian River system was inconclusive. Behnke (1976) reported a collection of pure Rio Grande cutthroat trout from Ricardo Creek, a tributary to the Canadian River, Las Animas County, Colorado. In a report to the New Mexico Department of Game and Fish, Behnke (1982) concluded that the Rio Grande cutthroat trout is native to the Canadian drainage.

Currently, populations of Rio Grande cutthroat trout are extant in southern Colorado and in four drainages in New Mexico; the Rio Grande, the Pecos, the Canadian, including the Mora, and the Tularosa basin (Sublette et al., 1990).

Rio Grande sucker, *Catostomous plebeius*, was first described by Baird and Girard (1854) and later reported on by Koster (1957). Its current distribution is reported as the Rio Grande, above the 36th parallel, its tributaries, primarily north of the 35th parallel, and the Mimbres River. Introduced populations of Rio Grande sucker also occur in the headwaters of the Gila River, the Rio Hondo (Pecos drainage) and in the San Francisco drainage, Sacramento Mountains (Sublette et al., 1990). Populations of this species also inhabit six river basins encompassing three states of Mexico (Smith, 1966; Hendrickson et al., 1980; Sublette et al., 1990). Rio Grande sucker co-occurs with Rio Grande cutthroat trout and with other exotic salmonids where only Rio Grande cutthroat were once present.

Rio Grande sucker are found in small to large, middle elevation streams with gravel/cobble/rubble substrates. They can also be found in backwater, beaver ponds, and pools proximate to riffles. Major spawning efforts occur in spring over medium gravel (8-16 mm) (Calamusso and Rinne in prep; Sublette et al., 1990). Koster (1957) suggested a second spawning in the fall. Rinne (1995a) during a study of the reproductive biology of the Rio Grande sucker in the Rio de las Vacas, did not find the autumnal spawning evident. The species is classified as a benthic lithophil (Mike Hatch, New Mexico Game and Fish Department, Pers. comm.) feeding on periphyton algae, and benthic invertebrates scraped from rocks with its cartilaginous upper mandible.

The Rio Grande sucker is listed as endangered in the state of Colorado, where one population exists in Hot Creek, a tributary to the Conejos River. Substantial populations are extant in New Mexico, however, there is concern that the species may be declining. Calamusso (1992) documented the absence of Rio Grande sucker in two watersheds of the Carson National Forest where prior records indicated its presence. Decline of the Rio Grande sucker is believed to be due to competition and genetic swamping by the white sucker, *Catostomus commersoni* (Rinne, 1995).Rio Grande chub, *Gila pandora*, were first reported and described from the Sangre de Cristo pass in the headwaters of the Rio Grande basin , New Mexico (Cope, 1871). Rio Grande chub are distributed in the Rio Grande, Canadian, and Pecos River drainages. Preferring pools in small to moderate streams, the species is also commonly associated

with instream woody debris and undercut banks (Rinne, 1995b). Spawning occurs in late spring and early summer. Rinne (1995b) found Rio Grande chubs exhibited a bi-modal spawning pattern in the Rio de las Vacas. Chubs had an extended spawning peak in spring (March to June) followed by a briefer, less marked autumnal spawning event. Nest construction and parental care was not observed (Koster, 1957). The species is a mid-water carnivore feeding on zooplankton, aquatic insects and juvenile fish. Detritus is also taken in limited amounts (Sublette et al., 1990). Currently, information is sparse on the ecology and life history on this species (Rinne, 1995b). The status of the Rio Grande chub in New Mexico is considered stable and reproducing (Sublette et al., 1990).

Studies were initiated in 1994 by the USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, in cooperation with New Mexico State University, because of:

1. The lack of knowledge of the ecology of these three native species,
2. The sensitive status of these species,
3. The inherent ecological and cultural value of these species, and
4. These species are the under the auspices of ecosystem management.

The main objectives of study were:

1. To develop a comprehensive statement on the distribution of Rio Grande cutthroat trout, the Rio Grande sucker, and the Rio Grande chub and
2. To define the co-occurrence of the three species in an effort to help resource professionals better manage these species.

OBJECTIVES

This paper discusses: 1) the relative distribution of the Rio Grande cutthroat trout, Rio Grande sucker and Rio Grande chub on the Carson and Santa Fe National Forests, 2) the co-occurrence of the Rio Grande sucker and chub with Rio Grande cutthroat trout, and 3) the comparative elevation, water temperature and gradient in reaches inhabited by these three species.

STUDY AREA

The study area comprised the Carson and Santa Fe National Forests, of north-central New Mexico (Figure 1). The Carson National Forest encompasses 563,185 ha and the Santa Fe 634,230 ha of National Forest System Lands. These Forests are administrative units of the Southwestern Region of the Forest Service, U.S. Department of Agriculture.

The landscape is generally mountainous with elevations ranging from 1,708 m in low elevation grasslands to Wheeler Peak at 4,011 m located on the Carson National Forest. North-central New Mexico can be characterized by a mild climate with cool summers, moderate winter snows, and many days of sunshine. Air temperatures vary from -31.70 c to 100 c in the winter. Summer air temperatures vary from -1.10°c to 350°c. Extended periods of heat or cold are rare.

Streams on the Carson and Santa Fe National Forests range from low elevation, low gradient streams to high elevation, high gradient streams, dominated by a boulder/cobble substrate. Riparian vegetation is well developed on most streams

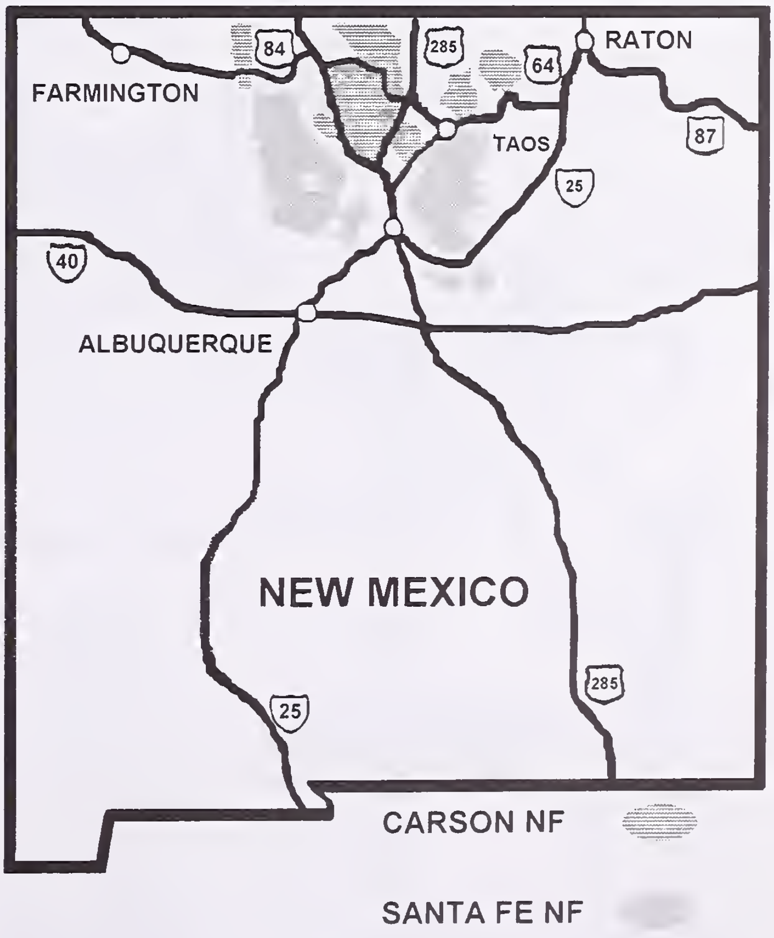


Figure 1. Carson and Santa Fe National Forest, New Mexico.

in the absence of livestock grazing. All streams surveyed were potentially impacted by one or more forest multiple use activities: logging, mining, road building, livestock grazing, and recreation.

METHODS AND MATERIALS

A review of the published literature, museum records and unpublished agency reports on the Rio Grande cutthroat trout, sucker and chub was conducted to determine known distributions of these species. Middle elevation tributaries to the Rio Grande that had no prior records of these species were selected for field investigations. Ichthyofauna of streams surveyed was sampled between June and August, 1994 using a Smith-Root Model 12 back-pack electrofisher. Fish captured were weighed, measured, sexed, and released alive to the stream.

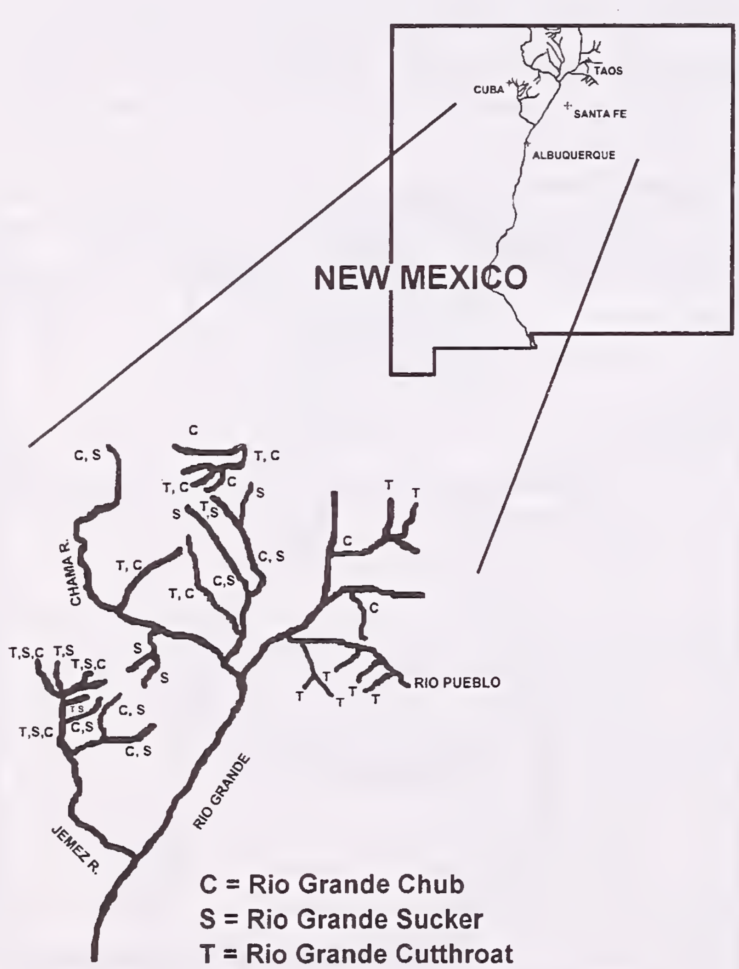


Figure 2. Distribution of Rio Grande chub, Rio Grande cutthroat and Rio Grande sucker in Carson and Santa Fe National Forest, New Mexico.

Table 1. Streams surveyed on the Carson and Santa Fe National Forests, 1994.

Carson NF streams	Santa Fe NF streams
Rio San Antonio	*Rio Guadalupe*
Canjilon Creek	*Rio de las Vacas*
Tusas Creek	*Rio de las Palomas*
Little Tusas Creek	*American Creek*
Tienditas Creek	*Clear Creek*
Rio Chiquito	*Chihauhuenones Creek*
Frijoles Creek	*Canones Creek*
Rito de Olla	*Polvedera Creek*
Rio Grande del Rancho	*Coyote Creek*
Rio Pueblo	*Rito Resumidero*
Canada de Osha	*Rio Puerco*
Comales Canyon	*Rito Redondo*
Agua Piedras	*Rito Capulin*
Canada Tio Maes	*Canyoncito Creek*
Rio Flechado	*Corrales Creek*
Gallegos Canyon	
San Cristobal Creek	
Cabresto Creek	
Rito del Medio	
Rio de las Trampas	
Rio San Leanardo	
Yerba Creek	
Italianos Creek	

RESULTS

Thirty eight streams were surveyed, (23 on the Carson and 15 on Santa Fe National Forest) for presence/absence and co-occurrence of Rio Grande cutthroat trout, Rio Grande sucker, and Rio Grande chub in 1994 (Table 1). Of the streams surveyed, seven streams on the Carson were identified as new distributions for the Rio Grande cutthroat trout. Nine streams, two on the Carson and seven on the Santa Fe National Forest, contained Rio Grande sucker (Figure 2). Rio Grande chub were found in five streams on the Santa Fe and three streams on the Carson. Co-occurrence of the Rio Grande cutthroat trout with the Rio Grande sucker and chub was documented in two streams on the Carson and six streams on the Santa Fe National Forest.

Rio Grande cutthroat trout distributions

Upon completion of a review of agency records and the 1994 field season, 93 populations of Rio Grande cutthroat trout have been identified for the Carson and Santa Fe National Forests (Stumpf 1993). Purity among these populations range from grade F, which is less than 25% pure, to grade A, which is 95-100% pure.

Seven are new locations identified through field efforts in 1994, an increase in known locations of 8.0%. They are Canada de Osha, Comales Canyon, Agua Piedras, Rio San Leanardo, Rio de las Trampas, Yerba Canyon and Italianos Creek. All are located on the Carson National Forest. Table 2 lists the distributions, elevations, and gradients of these streams; Table 3 shows number and size of Rio Grande cutthroat captured in these streams. Knowledge of Rio Grande cutthroat distribution was expanded for two streams on the Santa Fe National Forest; American Creek and Rito de Las Palomas. Electrofishing surveys found populations of Rio Grande cutthroat trout extant in both streams to the upper reaches.

Rio Grande sucker distributions

A total of 14 populations of Rio Grande sucker were found to occur within the study area. Three streams on the Carson and eleven streams on the Santa Fe contain the native sucker. Distribution, gradient, and elevation of Rio Grande sucker by stream are listed in Table 4.

Subjective observations indicated that streams in which Rio Grande sucker occurred held stable populations. Relative abundance estimates were performed in 1992, 1994 and 1995 and are currently being evaluated for population trends. Number and size of Rio Grande sucker captured in the study area in 1994 are shown in Table 5.

Table 2. New distributions for Rio Grande cutthroat trout, Carson National Forest, 1994.

Stream	UTM	Gradient (%)	Elev. (m)
Canada de Osha	446050E,400224N	3.0	2,400
	to		
	448140E,399565N	15.0	3,277
Comales Creek	447750E,4001190N	8.0	2,540
	to		
	448640E,3999620N	16.0	2,730
Agua Piedras	452640E,3998770N	9.0	2,583
	to		
	451490E,3993150N	12.0	3,669
Rio de las Trampas	429450E,4001150N	3.0	2,209
	to		
	442640E,3984480N	12.0	3,454
Rio San Leanardo	439360E,3988900N	5.0	2,720
	to		
	441460E,3984230N	12.0	3,748
Italianos Creek	455620E,4048670N	14.0	2,652
	to		
	453910E,4051400N	15.0	3,239
Yerba Creek	453430E,4046970N	10.0	2,497
	to		
	451320E,4050710N	18.0	3,436

Table 3. Number and size of Rio Grande cutthroat trout sampled at new localities, Carson National Forest, 1994.

Stream	n	Mean length (mm)	Length range (mm)	Mean weight (g)	Length range (g)
Canadade Osha	13	145.7	69.0 - 232.0	34.1	3.0 - 08.0
Comales Creek	13	209.9	93.0 - 163.0	26.4	1.0 - 80.0
Agua Piedras	8	155.0	99.0 - 211.0	45.6	8.0 - 96.0
Riodelas Trampas	18	180.8	100.0 - 250.0	76.2	10.0 - 247.0
Rio San Leanardo	5	201.6	134.0 - 296.0	110.6	20.0 - 310.0
Italianos Creek	14	146.5	60.0 - 227.0	38.8	0.5 - 110.0
Yerba Creek	24	244.8	115.0 - 230.0	100.4	11.0 - 110.0

Table 4. Distribution of Rio Grande sucker, Carson and Santa Fe National Forests, 1994.

Stream	UTM	Gradient (%)	Elev. (m)
Carson NF			
Rio Tusas	T25N,R9E,S19	1.0	1,991
	to 392400E,4066800N	2.7	2,785
Little Tusas	396710E,4064210N	1.0	2,692
	to 393000E.4070400N	4.0	2,914
Rio Vallecitos	T25N,R9E,S19	1.0	1.991
	to 388300E,4059790N	1.0	2,8
Santa Fe NF			
Jemez River	35100E,3965950N	0.05	1,717
	to 343130E,3946320N	1.0	2,072
East Fork, Jemez River	351500E,395950N	2.0	2,072
	to 363630E,3965670N	1.5	2,548
San Antonio Creek	351500E,3965950N	1.25	2,072
	to 351780E,3986540N	1.75	2,350
Rio Guadalupe	342240E,394855O	1.0	1,736
	to 338490E,3965220N	1.5	2,205
Santa Fe NF (Cont'd)			
Rio de las Vacas	338490E,3965220N	1.5	2,205
	to 337030E,3985120N	4.0	2,540
Rito de las Palomas	338460E,3984370N	1.0	2,485
	to 339060E,3986460N	2.5	2,589
American Creek	338460E,3984710N	1.0	2,500
	to 340070E,3986990N	2.5	2,604
Clear Creek	337560E,398452ON	0.75	2,500
	to 335490E,3984900N	4.0	2,572
Rio Cebolla	338490E,3965220N	1.5	2,205
Rock Creek	338440E.3983420N	2.0	2.482
	to 339200E.398398ON	3.5	2.497
Canones Creek	369970E,4001820N	2.5	2,120
Polvedera Creek	371300E,4040900N	1.0	2,055

Table 5. Number and size of Rio Grande sucker sampled on the Carson and Santa Fe National Forests, 1994.

Stream	n	Mean length (mm)	Length range (mm)	Mean weight (mm)	Weight range (mm)
Carson NF					
Rio Tusas	56	111.3	51.0 - 162.0	14.4	1.0 - 40.0
Little Tusas*					
Rio Vallecitos*	61	133.7	70.0 - 195.0	37.6	6.0 - 95.0
Santa Fe NF					
Rio Guadalupe	13	164.5	105.0 - 197.0	50.1	11.0 - 77.0
Rio de las Vacas	24	168.7	112.0 - 192.0	50.5	9.0 - 82.0
Rito de las Palomas	17	95.2	40.0 - 140.0	10.1	0.5 - 26.0
American Creek	16	105.4	40.0 - 165.0	18.31	0.5 - 54.0
Clear Creek	4	124.5	97.0 - 135.0	19.0	0.5 - 39.0
Canones Creek	8	121.5	43.0 - 198.0	31.4	0.5 - 78.0
Polvedera Creek	50 YOY-adult				

Rio Grande chub distributions

A review of museum records and field surveys conducted in 1994 has identified and confirmed 17 populations of Rio Grande chub in the study area; 9 on the Carson and 8 on the Santa Fe National Forest (Tables 6, 7). The species is widely distributed, and populations are considered stable on both Forests. Rio Grande chub were extant in middle elevation streams where elevations ranged from 1,717 to 2,810 meters. Gradients within reaches of Rio Grande chub presence were measured at 2% or less. Chub were never found in a reach with a gradient above 2% unless there were long (30 m+) pools/runs within the reach that exhibited gradients of 2% or less. Distribution, elevation and gradients of streams containing Rio Grande chub are shown in Tables 6 and 7.

A total of 82 Rio Grande chub were collected in 1992 on the Carson, and 34 were sampled on both the Carson and Santa Fe in 1994. Tables 8 and 9 list the number and size of Rio Grande chub sampled on the Carson and Santa Fe National Forests in 1994.

Table 6. Distribution of Rio Grande chub, Carson National Forest, 1994.

Stream	UTM	Gradient (%)	Elev. (m)
Rio de los Pinos	396650E,4090750N	0.80	2,640
	to		
	384930E,4093390N	3.0	2,655
Rio San Antonio	406360E,4094680N	1.25	2,690
	to		
	390380E,408110N	2.0	2,810
Rio Nutrias	392650E,4076720N	1.5	2,736
	to		
	392650E,4076720N	2.0	2,767
Tio Grande	397640E,4079790N	1.25	2,706
Rio Tusas	T25N,R9E,S19	1.0	1,991
	to		
	408830E,4044090N	3.5	2,256
Rio Vallecitos	T25N,R9E,S19	1.0	1,991
	to		
	395200E,4048850N	3.0	2,462
El Rito	394900E,4014100N	0.9	1,905
	to		
	386020E,4037700N	2.0	2,570
Canjilon Creek	364430E,4022400N	1.5	1,982
	to		
	376690E,4041550N	3.0	2,644
Rio Grande del Rancho	447010E,4020410N	1.4	2,178
	to		
	447950E,4015850N	2.2	2,255

Table 7. Distribution of Rio Grande chub, Santa Fe National Forest, 1994.

Stream	UTM	Gradient (%)	Elev. (m)
Jemez River	343130E,3946320N	0.05	1,717
	to		
	351500E,3965950N	1.0	2,072
East Fork, Jemez River	351500E,3965950N	2.0	2,072
	to		
	363630E,395670N	1.5	2,598
San Antonio Creek	351500E,3965950N	1.25	2,072
	to		
	351780E,3971150N	1.4	2,350
Rio Guadalupe	342240E,3948550N	1.0	1,736
	to		
	338490E,3965220N	1.5	2,205
Rio de las Vacas	338490E,3965220N	1.5	2,205
	to		
	337560E,3984520N	2.0	2,500
Rio Cebolla	338490E,3965220N	1.5	2,205
Rito de las Palomas	338250E,3984370N	1.0	2,485
	to		
	338460E,3984710	1.0	2,500
American Creek	338460E,3984710N	1.0	2,494
	to		
	340020E,3986540N	1.75	2,577
Clear Creek	337560E,3984520N	0.75	2,500
	to		
	335490E,3984900N	4.0	2,572

Table 8. Number and size of Rio Grande chub sampled on the Carson National Forest, 1994.

Stream	n	Mean length (mm)	Length range (mm)	Mean weight (mm)	Weight range (mm)
R. Grande del Rancho*	3	130.0	108.0 - 145.0	26.3	14.0 - 38.0
Rio de los Pinos*	6	73.2	62.0 - 92.0	5.3	2.0 - 12.0
Rio San Antonio	26	89.0	20.0 - 142.0	4.8	0.5 - 30.0
Rio Nutrias*	22	80.3	40.0 - 142.0	7.1	0.5 - 9.0
Tio Grande*	2	114.5	92.0 - 37.0	32.0	16.0
Rio Tusas	5	124.8	100.0 - 152.0	12.4	3.0 - 30.0
Rio Vallecitos*	82	116.5	43.0 - 178.0	17.3	0.5 - 85.0
El Rito Creek*	97	107.9	25.0 - 176.0	21.4	0.5 - 64.0
Canjilon Creek*	19	87.7	43.0 - 123.0	9.5	0.5 - 51.0

Sampled by Carson NF personnel, 1992.

Table 9. Number and size of Rio Grande chub sampled on the Santa Fe National Forest, 1994.

Stream	n	Mean length (mm)	Length range (mm)	Mean weight (mm)	Weight range (mm)
Rio Guadalupe	1	80.0	-	3.0	-
Rio de las Vacas	9	123.0	112.0 - 136.0	16.7	13.0 - 22.0
Rito de la Palomas	3	103.7	75.0 - 140.0	14.3	5.0 - 29.0
American Creek	2	101.5	75.0 - 128.0	7.7	0.5 - 15.0

Co-occurrence of species

Ten streams on the Carson and Santa Fe National Forests exhibited co-occurrence of the Rio Grande cutthroat trout with the Rio Grande sucker or chub (Table 10).

Co-occurrence of Rio Grande cutthroat trout with the Rio Grande sucker was documented in one stream on the Carson (Rio Tusas) and five streams (Rio de las Vacas, Rito de las Palomas, American Creek, Clear Creek and Canones Creek of Abiquiu Reservoir on the Santa Fe. The location of co-occurrence, gradient and elevation of these streams are in Table 11.

Rio Grande cutthroat trout were found to co-occur with Rio Grande chub in four streams on the Carson. They were Rio Nutrias, Rio San Antonio, El Rito Creek and Canjilon Creek. On the Santa Fe National Forest co-occurrence of Rio Grande cutthroat trout with Rio Grande chub was documented in two streams; Rio de las Palomas and American Creek. Location, gradient and elevation of these stream reaches are shown in Table 12.

Table 10. Co-occurrence of Rio Grande cutthroat trout, sucker and/or chub, Carson and Santa Fe National Forests, 1994.

Stream	Rio Grande cutthroat trout	Rio Grande sucker	Rio Grande chub
Carson NF			
Rio Tusas	X	X	
Canjilon Creek	X		X
El Rito	X		X
Rio San Antonio	X		X
Rio Nutrias	X		X
Santa Fe NF			
Rio de las Vacas	X	X	X
Rito de las Palomas	X	X	X
American Creek	X	X	X
Clear Creek	X	X	X
Canones Creek	X	X	

Totals of 43 Rio Grande cutthroat trout, three Rio Grande sucker and 46 Rio Grande chub were sampled in reaches of co-occurrence on the Carson. Number and size of these species are compiled by stream in Table 13. For the Santa Fe, 53 Rio Grande cutthroat trout, 48 Rio Grande sucker and 10 Rio Grande chub were sampled in reaches of the streams that exhibited co-occurrence. Table 14 shows the number and size of these fishes.

DESIRED FUTURE CONDITION

To manage Rio Grande cutthroat trout, sucker and chub resources effectively, managers of all agencies must have the latest information on their distribution and status. It was with this goal in mind that we initiated our study. Information concerning these species is dynamic, that is, we are gaining information on new populations and monitoring changes or maintenance of existing populations. The addition of seven new populations of Rio Grande cutthroat trout and two of Rio Grande sucker during one season of field work substantiates that much is still unknown about the distribution and status of both these species. Future goals for this study are to continue to document new distributions of Rio Grande cutthroat trout and sucker, and to describe the physical and biological processes involved in delimiting populations of these species.

The desired future condition for the three species of fish is to maintain wild, self-sustaining populations of each. Specific strategies will need to be developed and implemented for each species. Results from our study indicate that Rio Grande chub are widely distributed in the study area and populations are stable. Protection of wild chub populations from habitat loss, alteration or introduction of non-native species will achieve the desired future condition for this species.

Rio Grande sucker are also distributed throughout the study area, but are considered to be vulner-

Table 11. Co-occurrence of Rio Grande cutthroat trout and Rio Grande sucker, Carson and Santa Fe National Forests, 1994.

Stream	UTM	Gradient (%)	Elev. (m)
Carson NF			
Tusas Creek	392400E,4066800N	1.5	2,770
Santa Fe NF			
Rio de las Vacas	337240E,3984850N	2.5	2,521
	to		
	337030E,3985120N	4.0	2,540
Rito de las Palomas	338250E,3984370N	1.0	2,485
	to		
	339060E,3986460N	2.5	2,589
American Creek	338460E,3984710N	1.0	2,494
	to		
	340020E,3986540N	1.75	2,577
Clear Creek	337560E,3984520N	0.75	2,500
	to		
	335570E,3984710N	1.5	2,558
Canones Creek	369970E,4001820N	2.5	2,125

Table 12. Co-occurrence of Rio Grande cutthroat trout and Rio Grande chub, Carson and Santa Fe, 1994.

Stream	UTM	Gradient (%)	Elev. (m)
Carson NF			
Canjilon Creek	364430E,4022400N	1.5	1,982
	to		
	376690E,4041550N	3.0	2,644
El Rito	387570E,4029110N	2.5	2,337
	to		
	386020E.4037700N	2.0	2,570
Rio San Antonio	399430E,4079640N	1.25	2,704
Nutrias Creek	394520E,4078370N	1.5	2,730
	to		
	392640E,4076720N	2.0	2,767
Santa Fe NF			
Rito de las Palomas	338250E,3984460N	1.0	2,580
	to		
	392640E,4076720N	2.0	2,495
American Creek	338460E,3984710N	1.0	2,495
	to		
	340020E,3986540N	1.75	2,577
Clear Creek	337560E,3984520N	0.75	2,500
	to		
	335570E,3984710N	1.5	2,558

Table 13. Number and size of Rio Grande cutthroat trout, sucker and chub found in co-occurrence, Carson National Forest, 1994.

Stream	n	Mean length (mm)	Length range (mm)	Mean weight (mm)	Weight range (mm)
Tusas Creek					
RG cutthroat trout	3	153.0	70.0 - 231.0	53.3	3.0 - 120.0
Rio Grande sucker	3	100.0	81.0 - 109.0	10.3	5.5 - 13.0
Rio San Antonio					
RG cutthroat trout	3	110.3	108.0 - 115.0	11.0	10.0 - 12.0
Rio Grande chub	24	81.2	45.0 - 142.0	6.1	1.0 - 30.0
Rio Nutrias					
RG cutthroat trout	2	306.0	297.0 - 315.0	305.0	300.0 - 310.0
Rio Grande chub	16	57.1	40.0 - 96.0	2.4	0.5 - 9.0
Canjilon Creek					
RG cutthroat trout	8	160.1	96.0 - 212.0	54.0	8.0 - 103.0
Rio Grande chub	6	47.0	43.0 - 60.0	1.2	1.0 - 2.0
El Rito					
RG cutthroat trout	27	145.4	82.0 - 264.0	-	-
Rio Grande chub	94	108.9	25.0 - 176.0		

Table 14. Number and size of Rio Grande cutthroat trout, sucker and chub found in co-occurrence, Santa Fe National Forest, 1994.

Stream	n	Mean length (mm)	Length range (mm)	Mean weight (mm)	Weight range (mm)
Rio de las Vacas					
RG Cutthroat trout	1	184.0	- 50.0	-	
Rio Grande sucker	3	183.0	178.0 - 188.0	58.7	50.0 - 68.0
Rito de las Palomas					
RG cutthroat trout	7	136.4	96.0 - 169.0	25.7	8.0 - 42.0
Rio Grande sucker	17	95.2	40.0 - 140.0	10.1	0.5 - 26.0
Rio Grande chub	3	103.7	75.0 - 140.0	14.3	5.0 - 29.0
American Creek					
RG cutthroat trout	26	150.0	105.0 - 231.0	36.9	7.0 - 118.0
Rio Grande sucker	16	105.4	40.0 - 165.0	18.3	0.5 - 54.0
Rio Grande chub	2	128.0	-	15.0	
Clear Creek					
RG cutthroat trout	7	145.9	136.0 - 150.0	28.1	20.0 - 38.0
Rio Grande sucker	4	124.5	97.0 - 135.0	19.0	6.0 - 25.0
Rio Grande chub	5	115.0	55.0 - 155.0	16.3	0.5 - 39.0
Canones Creek					
RG cutthroat trout	12	212.6	105.0 - 275.0	124.7	16.0 - 208.0
Rio Grande sucker	8	121.5	43.0 - 198.0	31.4	0.5 - 70.0

able to reductions in range because of the introduced white sucker. Remaining stocks of Rio Grande sucker need to be monitored and protected. If further declines are observed, such as has occurred in the State of Colorado and on the Carson National Forest, management efforts may be required to accomplish this goal. Research needs to be implemented in an effort to identify the mechanisms by which the white sucker contributes to the decline of the native sucker.

Rio Grande cutthroat trout has been reduced to 5-7% of its former range. The decline continues. Remaining populations of pure Rio Grande cutthroat need to be protected, and management efforts need to continue to reintroduce the species into its former range. Research efforts should focus on the role that non-native salmonids have in delimiting distribution, abundance, and sustainability of this rare southwestern trout.

LITERATURE CITED

Anonymous. 1877. Rio Grande Trout. Forest and Stream, 9(4): 67.

Behnke, R. J. 1982. Evaluation of 1982 collections of cutthroat trout from New Mexico. New Mexico Dept. of Game and Fish, Santa Fe, NM. 38pp.

Calamusso, B. 1992. Current distribution of *Catostomus plebeius* and *Gila pandora* on the Carson National Forest, New Mexico with Needham, P. R. and R. Gard. 1964. A new trout preliminary comment on habitat preferences. Proc. Desert Fishes Council 24: 63-64.

Calamusso, B. and J. N. Rinne. In prep. Substrate utilization of spawning Rio Grande Sucker, *Catostomus plebeius*) in northern New Mexico.

Cope, E. D. 1886. The most southern salmon. Am. Nat., 20(8): 735.

Girard, W. 1856. Notice upon the species of the genus *Salmo* of authors observed chiefly in Oregon and California. Proc. Acad. Nat. Sci. Philad., 8: 217-220.

Hendrickson, D. A., W. C. Minckley, R. R. Miller, D. J. Siebert, and P. H. Minckley. 1980. Fishes of the Rio Yaqui Basin, Mexico and the United States. J. Arizona-Nevada Acad. Sci. 15(3): 65-106.

Koster, W. J. 1957. Guide to the fishes of New Mexico. Univ. New Mexico Press, Albuquerque. from central Mexico, *Salmo chrysogaster*, the Mexican golden trout. Copeia (1): 169-173.

Propst, D. L. 1976. Taxonomic analysis of cutthroat trout, *Salmo clarki* ssp., collected in northern New Mexico, 1976. Final report to New Mexico Dept. of Game and Fish, contract 516-64-22. 77pp.

Rinne, J. N. 1995a. Reproductive biology of the Rio Grande sucker, *Catostomus plebeius*, (Cypriniformes) in a montane stream, New Mexico. The Southwestern Naturalist 40 (2): 237-241.

Rinne, J. N. 1995b. Reproductive biology of the Rio Grande chub, *Gila pandora*,(Cypriniformes) in a montane stream, New Mexico. The Southwestern Naturalist 40(1): 107-110.

Smith, G. R. 1966. Distribution and evolution of the North American catostomid fishes of the subgenus *Pantosteus*, genus *Catostomus*. Univ. Michigan Mus. Zool. Misc. Publ. No. 129, 132pp.

Stork, E. F. 1975. Distribution of Rio Grande cutthroat trout in the Santa Fe National Forest. M.S. Thesis, Colorado State University, Fort Collins, CO. 55pp.

Stumpff, W. K. 1993. Rio Grande trout management grant. New Mexico Dept. Game and Fish Report. #11. 18pp.

Sublette, J. E., M. D. Hatch, and M. Sublette. 1990. The fishes of New Mexico. Univ. of New Mexico Press, Albuquerque.

Wallace, R. L. and R. J. Behnke. 1974. Report on recent collections of Rio Grande cutthroat trout: Evaluation of relative purity of populations in recent collections. Colo. Coop. Fish. Unit, 10pp.

Wernsman, G. R. 1973. Systematics of native Colorado cutthroat trout. M.S. Thesis. Colorado State University, Fort Collins, CO. 57pp.

Bat species using water sources in pinyon-juniper woodlands

Alice Chung-MacCoubrey[1]

Abstract.—Much is yet to be learned about the importance of bats in Southwestern ecosystems, their ecological requirements, and how habitats should be managed to sustain these important species. A first step towards these goals is to determine what species exist in different habitats and across what geographic ranges. The objective of this study was to identify the bat species which use pinyon-juniper habitats of the Middle Rio Grande Basin. Ten pinyon-juniper sites with permanent water on the Cibola National Forest were mist netted four times from May to September 1995. Sixteen bat species were captured from the 10 sites. The number of sites a species was captured at and frequency of capture varied according to species.

INTRODUCTION

Most North American bats are primarily insectivorous. Their roles in Southwestern ecosystems include regulation of insect populations, subsequent effects on insect-related ecological processes (such as herbivory, pollination, and disease transmission), and nutrient cycling and distribution. Despite their importance to many ecosystem processes, bats have largely been ignored, most likely due to their lack of public appeal and the difficulty with which they are studied. Much of the information needed to manage habitats for bats, such as foraging and roost requirements, is unknown. Without greater attention to bats and their ecological requirements, we cannot assure that their roles and contributions in Southwestern ecosystems will be sustained. The first step in investigating bats and their requirements is to determine species distributions and habitat use. The objective of this study was to determine which bat species use pinyon-juniper habitats along the Middle Rio Grande. Based on this research, further studies may be designed to focus on structures and specific areas within habitats that different species use for roosting, foraging, and reproduction.

METHODS

Bats were captured by placing mist nets over permanent bodies of water at 10 different pinyon-juniper sites throughout 5 mountain ranges (the Sandias, Manzanos, Magdalenas, Gallinas, and San Mateos) of the Cibola National Forest (fig. 1). Water sources were either dirt stock tanks, open-topped steel water tanks, or stream sites. Each site was netted 4 times between May and September 1995. Nets were typically open from sunset to 1:00 a.m.. After species, sex, age, reproductive status, and body measurements were recorded, bats were weighed and released (fig. 2).

[1] *Research Wildlife Biologist, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Albuquerque, NM.*

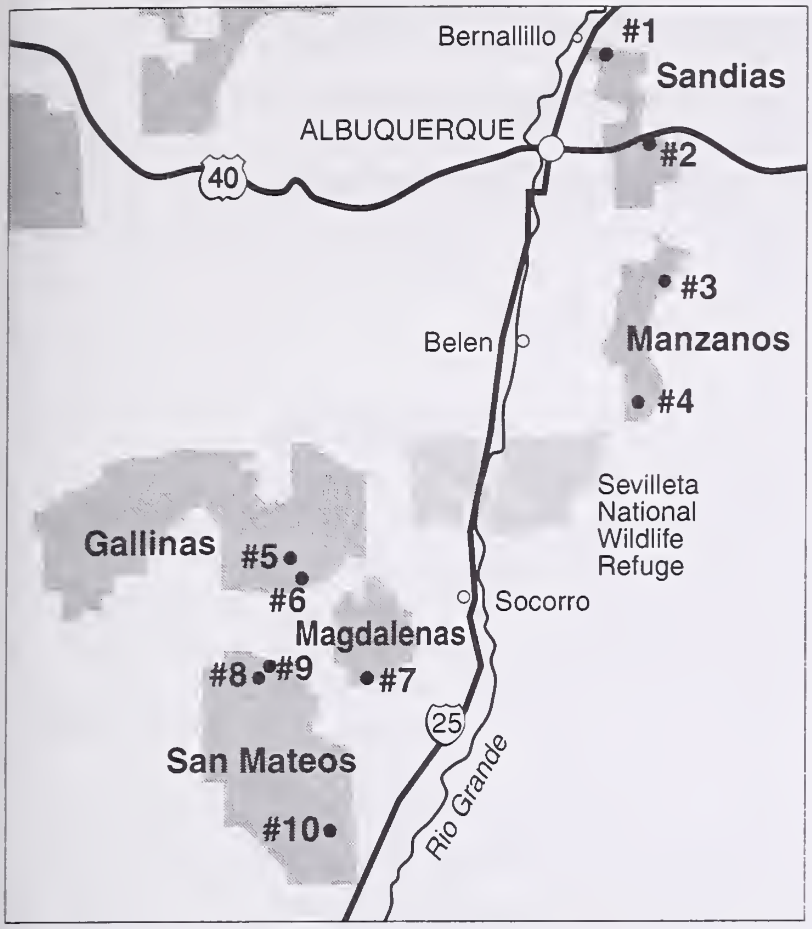


Figure 1. Ten sites on the Cibola National Forest with permanent water were mist netted to examine bat species composition in pinyon-juniper woodlands.

Figure 2. Captured bats were identified to species. Age was determined by examining wing bones.

RESULTS

A total of 16 species were captured from the 10 pinyon-juniper sites (Table 1). Captures in a single night ranged from 0-134 bats ($\overline{\chi} = 27 \pm 30$). Total captures were generally lower in the Sandia and Manzano mountains. The maximum number of captures in a single night occurred at a spring-fed pond and riparian area amongst steep pinyon-juniper in the Magdalenas.

California myotis, small-footed myotis, long-legged myotis, big brown bats, silver-haired bats, and hoary bats were caught at most of the sites (7-

Table 1. Sixteen bat species were captured in pinyon-juniper habitat. The number of sites each species was captured at and current federal status of each species are reported.

Species	Number of sites	Federal status
California & small-footed myotis[a] (*Myotis californicus & ciliolabrum*)	10	Category 2 Candidate[b]
Long-legged myotis (*M. volans*)	8	Category 2 Candidate
Big brown bat (*Eptesicus fuscus*)	8	
Silver-haired bat (*Lasionycteris noctivagans*)	8	
Hoary bat (*Lasiurus cinereus*)	7	
Fringed myotis (*M. thysanodes*)	5	Category 2 Candidate
Mexican free-tailed bat (*Tadarida brasiliensis*)	5	
Long-eared myotis (*M. evotis*)	4	Category 2 Candidate
Southwestern myotis (*M. auriculus*)	4	
Yuma myotis (*M. yumanensis*)	3	Category 2 Candidate
Pallid bat (*Antrozous pallidus*)	2	
Little brown myotis (*M. lucifugus*)	1	Category 2 Candidate
Western pipistrelle (*Pipistrellus hesperus*)	1	
Allen's lappet-browed bat (*Idionycteris phyllotis*)	1	Category 2 Candidate
Spotted bat (*Euderma maculatum*)	1	Category 2 Candidate

[a] *These species cannot be reliably distinguished in the field and are thus reported together.*

[b] *Only* M. ciliolabrum *is a Category 2 Candidate species.*

Figure 3. A tail that extends well beyond the tail membrane distinguishes the Mexican free-tailed bat from other species.

Figure 4. The pallid bat. This species feeds on terrestrial insects such as crickets, centipedes, and scorpions.

Figure 5. The spotted bat. A single individual of this distinctive species was captured in the San Mateo Mountains.

10 sites). Fringed myotis, long-eared myotis, southwestern myotis, and Mexican free-tailed bats (fig. 3) were caught at approximately half (4-5) of the netting sites. Pallid bats (fig. 4), little brown myotis, Yuma myotis, western pipistrelles, Allen's lappet-browed bats, and spotted bats (fig. 5) were caught infrequently and at few sites.

DISCUSSION

This season, all or a large portion of the bat species that use water and other resources of pinyon-juniper habitats of the Cibola National Forest were identified. Many factors affect the species and number of bats captured, including weather, moon phase, site locations, overall availability of water, reproductive status of bats, changes in foraging patterns, previous captures, and ability to avoid nets (Reith 1982, Kunz and Kurta 1988). The lower number of total captures in the Sandia and Manzano mountains was likely due to the fewer number of suitable watering sites in pinyon-juniper habitats of these mountains (pers. obs.). Although many factors may affect netting results, mist netting provides information such as species composition, relative abundance, and timing of activities. Information from this study such as geographic distribution and habitat use by different bat species may be used by managers for making future status determinations of Federal Category 2 candidate species, managing bat habitat, and evaluating land management practices, and by researchers for designing future roost, foraging, and reproductive studies.

LITERATURE CITED

Kunz, Thomas H.; Kurta, Allen. 1988. Capture methods and holding devices. In: Kunz, T. H. Ecological and behavioral methods for the study of bats. Washington, D.C. Smithsonian Institution Press: 1-28.

Reith, Charles C. 1982. Insectivorous bats fly in shadows to avoid moonlight. Journal of Mammalogy 63(4):685-688.

Summer bird/vegetation associations in Tamarisk and native habitat along the Pecos River, southeastern New Mexico

M.F. Livingston[1] and S.D. Schemnitz[2]

Abstract.—The middle Pecos River lies in the short-grass prairie ecotype and lacked a substantial woodland community prior to tamarisk (*Tamarisk chinensis*) invasion. Tamarisk control is a concern for land managers on the Pecos River and other Southwestern riparian systems. Our research is part of a long term study investigating hydrological and wildlife response to tamarisk removal on the Pecos river in Eddy County, New Mexico. Our objectives were to collect baseline data and describe avian/vegetation associations at the treatment site and two non-treatment (control) sites prior to herbicide application. In 1994 and 1995, we estimated bird mean abundance and species richness in tamarisk and grassland habitats, described vegetational structure and species composition, and compared bird species abundance, richness, and composition. The treatment site and control site 1 (Brantley Wildlife Management Area [BWMA]) had expansive monotypic stands of tamarisk. Control site 2 (Bitter Lake National Wildlife Refuge [BLNWR]) had expansive areas of grassland. Bird mean abundance was significantly higher at the treatment site and BWMA in 1994 than 1995. BWMA was similar to the treatment site in vegetation, but consistently had higher bird abundance and species richness. BLNWR had minimal vegetational structure and consistently had the lowest bird abundance and species richness values. Factors including vegetation structure, grazing, habitat patchiness, and human disturbance are offered to explain differences in bird community patterns between sites.

Tamarisk or saltcedar (*Tamarix chinensis*) was introduced to North America in mid-1800's from Eurasia as an ornamental and later for erosion control (Robinson 1965). This exotic has escaped cultivation and spread throughout Southwestern riparian ecosystems to encompass 15,688 ha along the lower Colorado River (Ohmart et al. 1977), and 28,800 ha along the Pecos River in New Mexico, and 87,200 ha in Texas (Hunter et al. 1985). Tamarisk out competes native vegetation in three ways:

- Secretes a salty exudate raising soil salinity above other species' tolerance,
- Creates a fire prone ground cover by shedding its leaves and sprouts vigorously after fire, and
- Creates a dense over-story which shades out other species (Sisneros 1991). As a consequence of its competiveness, tamarisk creates monotypic stands.

The middle Pecos Valley lies in the shortgrass prairie ecotype (Dick-Peddie 1993) and lacked a substantial woodland community prior to tamarisk invasion (Hildebrandt and Ohmart 1982). Historically, cottonwood (*Populus fremontii* var *wislizeni*)

[1] *Graduate Research Assistant, Fishery and Wildlife Sciences Department at New Mexico State University, Las Cruces, NM.*

[2] *Professor, Wildlife Science, New Mexico State University, Las Cruces, NM.*

gallery forest was restricted to localized, narrow bands adjacent to the river (e.g. Ft. Sumner, NM). Primary vegetation types were Chihuahuan grassland and Chihuahuan shrub (Dick-Peddie 1993).

Several studies have compared bird use of tamarisk versus native woodland vegetation. Results from that work indicated bird/tamarisk associations varied between geographic location. Negative associations were detected along the lower Colorado River and lower Rio Grande (Anderson et al. 1977, Engel-Wilson and Ohmart 1978, Anderson and Ohmart 1984). However, other studies have indicated positive associations along the Pecos River and Rio Grande for at least some species (Hunter et al. 1985, Hunter et al. 1988, Leal 1994, Ellis 1995). Only one study to date has compared bird use of tamarisk and native grassland vegetation (Hildebrandt and Ohmart 1982). Additional knowledge of tamarisk encroachment impacts on grassland birds is needed.

Our research is part of a long term study investigating hydrological and wildlife response to tamarisk removal on a privately owned 2000 ha plot adjoining to the Pecos river in Eddy County, New Mexico. Tamarisk is being killed with a Arsenal/Rodeo (Imazapyr/Glyphosate) mixture (SCS 1994). Our objectives were to collect baseline data and describe avian/vegetation associations at the treatment site and two non-treatment (control) sites prior to herbicide application. We estimated bird mean abundance and species richness in tamarisk and grassland habitats, described vegetational structure and species composition at the three sites, and compared bird species abundance, richness, and composition among dominant vegetation types.

STUDY AREA

We conducted the study in Eddy and Chaves counties, southeastern New Mexico. The treatment site was south of U.S. Highway 82 and north of the Rio Penasco on the west side of the Pecos River, near Artesia, New Mexico. Control site 1 was five km south of the treatment site situated within the state managed, 15,390 ha Brantley Wildlife Management Area (BWMA). Dominant woodland vegetation was tamarisk, dominant grassland vegetation was alkali sacaton (*Sporobolus aeroides*) with mixed shrubs of honey mesquite (*Prosopsis glandulosa*) and tamarisk. Kochia (*Kochia scoparia*) was present in expansive fields interspersed with tamarisk stands. Tamarisk density and distribution was variable, but decreased in density away from the river. Year-round grazing occurred at the treatment site; no grazing has occurred at BWMA for four years. Chihuahuan desert shrub bordered the east side of the river. Control site 2 was approximately 80 km north of the treatment site on the west side of the Pecos river at Bitter Lake National Wildlife Refuge (BLNWR). BLNWR was sampled only in 1995. Dominant riparian vegetation was alkali sacaton with scattered seep willow (*Baccharis spp.*) shrubs. Tamarisk was limited to small patches in oxbow lakes, areas proximate to the river and management impoundments, and scattered throughout grassland vegetation. All sites were located within the Pecos River floodplain. No grazing has occurred at BLNWR since the 1930's. Elevation of the study sites ranged from 997 to 1006 m at the treatment site and BWMA, and 1058 to 1074 m at BLNWR. Average annual temperature was 16 C, with extremes of -31 C in winter and 44 C in summer, and average annual precipitation from 1958 to 1994 was 32 cm. Most rainfall occurrs in July and August (Agr. Sci. Cen. at Artesia).

METHODS

We randomly placed eight line-transects (Buckland et al. 1993) at each site. Four transects were in tamarisk (habitat 1), and four transects were in mixed-shrub grassland (habitat 2) at the treatment site and at BWMA. At BLNWR, four transects were in habitat 2 and four were in grassland devoid of tamarisk (habitat 3). Habitat 3 was only present at BLNWR. Habitat 1 did not occur at BLNWR. All transects within a site were >200 m apart to ensure independence of bird surveys. All transects were 600 m long.

We counted birds along each transect three times from mid-May through the first week of July 1994 and 1995. Counts began one-quarter hour before sunrise and continued for two hours (Anderson and Ohmart 1977). We recorded all birds heard or seen within a distance of 100 m perpendicular to the transect. No surveys were

conducted during rain or in winds >10 km/hour (Skirvin 1981). We began surveys after a two minute acclimation period.

We sampled tamarisk density (trees/ha) using 5 X 100 m belt-transects. Six belt-transects were established perpendicular to each bird-transect at 100 m intervals. All tamarisk plants ≥1 m in height were counted as trees, tamarisk plants <1 m were counted as shrubs. We established points at 15 m and 50 m from the bird-transect within each belt-transect in habitat 1. We chose four trees systematically using the Point Centered-Quarter method (Cottam and Curtis 1956) at each point. Measurements for each tree included distance from point, height, and number of stems. In habitat 2, five trees were randomly chosen within each belt-transect for height measurements and stem counts. We sampled all available trees when less than five were present. We quantified shrub and herbaceous vegetation using a line-intercept method (Canfield 1941) in all three habitat types. Twelve 15 m lines were randomly located for measuring herbaceous vegetation and shrubs at 100 m intervals and on each side of a bird-transect. Grass and shrub height was measured every three meters along the line.

We summarized vegetation variables within each site for grassland and tamarisk dominated habitats. A multivariate analysis of variance procedure with orthogonal contrast statements (SAS 1990, p.905) was used to detect differences among sites and within sites between habitat types for tree variables. We expressed bird species mean abundance values as average number of detections for each species from three surveys at a transect. Bird species richness was expressed as total number of species enumerated along each transect for three surveys. Whittaker's Coefficient of Community was used to determine similarity of species between sites and habitat types (CC):CC = 2Sab/(Sa + Sb), where Sab is the number of species in common between two habitats, and Sa and Sb are the numbers of species in each of the two habitats, respectively (Whittaker 1975, Farley et al. 1995).

We tested all data for normality and used non-parametric tests when needed. We performed paired comparison t-tests to detect differences among years for bird mean abundance and species richness. We used a general linear model with orthogonal contrast statements to detect differences among sites and among habitat types within sites for bird mean abundance and species richness (SAS 1990, p.372, 618, 905). We considered differences significant at $P \leq 0.05$.

RESULTS

Vegetational characteristics

Mean values for tamarisk tree density, stem density, and average height were not different between the treatment site and BWMA in habitat 1 ($F=0.8593$; 3,48 df; $p=0.4687$) and in habitat 2 ($F=0.7757$; 3,43 df; $p=0.5140$) (Table 1). Mean values were different between the treatment site and BLWNR ($F=18.2484$; 3,43 df; $p=0.0001$) and between BWMA and BLNWR in habitat 2 ($F=12.9386$; 3,43 df; $p=0.0001$). At individual sites, differences existed in vegetation structure among habitat types (treatment: $F=57.0500$; 6,86 df; $p=0.0001$ and BWMA: $F=55.0130$; 6,78 df; $p=0.0001$).

Line intercept data showed a large percentage of leaf and woody debris in habitat 1 at the treatment site (66%) and BWMA (65%) (Table 2). Bare ground was prevalent (≥34%) at all sites in habitats 2 and 3. The primary herbaceous plant in habitats 2 and 3 was alkali sacaton. Few herbaceous (≤10%) and no shrub species were present in habitat 1. The dominant shrub in habitat 2 at the treatment site and BWMA was honey mesquite. Dominant shrubs in habitats 2 and 3 at BLNWR were iodine bush

Table 1. Means and standard deviations for tamarisk variables measured at three sites in summer 1994 and 1995, southeastern New Mexico.

Site habitat[1]	Tree/ha $\bar{x}$	Tree/ha SD	Stem/ha $\bar{x}$	Stem/ha SD	Tree height (m) $\bar{x}$	Tree height (m) SD
Treatment						
1	2,781	76	25,965	7,336	2.7	1.0
2	393	21	4,902	1,271	2.8	1.1
BWMA						
1	2,664	83	25,451	9,899	3.2	1.0
2	81	5	1,211	834	2.5	0.8
BLNWR						
2	155	9	1,619	1,019	1.9	1.0
3	0	0	0	0	0	0

[1] Habitat 1=Tamarisk dominated (only sampled at treatment site and BWMA), 2=Grassland with mixed shrubs, 3=Grassland devoid of tamamrisk (only sampled at BLNWR).

(*Allenrolfea occidentalis*) and seep willow (*Baccharis spp.*), respectively. Average grass height was lowest at the treatment site, intermediate at BWMA, and highest at BLNWR. Average shrub height was not available for the treatment site, and was lower at BWMA than BLNWR (Table 2).

Bird species mean abundance, richness, and composition

A total of 3,472 observations were made of 49 species for 1994 and 1995 combined. We excluded species with fewer than seven observations, resulting in 22 species for analyses (Table 3). More birds were detected in 1994 when data were pooled across sites (t=9.2741; 15 df; p=0.0001) and at each individual site (treatment: t=7.4464; 7 df; p=0.0001 and BWMA: t=5.8665; 7 df p=0.0004). We therefore performed separate analyses for each year.

Site comparisons for bird mean abundance and species richness yielded significant differences in several instances (Table 4). In all cases where differences were detected, BWMA had highest bird mean abundance and species richness, the treatment site had intermediate values, and BLNWR had lowest values (Table 3). Mean abundance and species richness were not different between habitat types at any of the sites in either year. All similarity values exceeded 0.52 for between site comparisons. BWMA and the treatment site had the highest similarity for all comparisons (0.70) in habitat 1 in 1994; they were least similar for all comparisons for habitat 2 in 1994 (0.52). Similarity values between habitat 1 and 2 were highest in 1994 (0.80) at BWMA and were lowest in 1995 (0.52) at BWMA.

Seven species were most commonly detected across all sites and habitats for both years. Mourning Dove was the most abundant species in habitat 1 for both years and was detected in all habitats and sites (Fig. 1 and Table 3). Also, it was the most frequently detected species in habitat 2 at the treatment site for both years and at BWMA in 1995. Northern Mockingbird and Brown-headed Cowbird were the next abundant species in habitat 1. Northern Mockingbird was absent only at BLNWR in habitat 3. Brown-headed Cowbird was detected at all sites and habitats. Cassin's Sparrow was most abundant in habitat 2 at BWMA in 1994, but did not occur at the treatment site in either year. Eastern and Western Meadowlarks were most commonly detected in habitats 2 and 3 at BLNWR and occurred at all sites. Lark Sparrow was absent in habitat 1 at the treatment site and habitat 3 at BLNWR (Fig. 1).

Table 2. Percent ground cover for three sites in summer 1994 and 1995, southeastern New Mexico.

	Site											
	Treatment				BWMA				BLNWR			
	Habitat 1[1]		Habitat 2		Habitat 1		Habitat 2		Habitat 2		Habitat 3	
Ground cover type	$\bar{x}$	*SD*	$\bar{x}$	*SD*	$\bar{x}$	*SD*	$\bar{x}$	*SD*	$\bar{x}$	*SD*	$\bar{x}$	*SD*
Herbaceous plants[2]	10	9.1	30	15.0	9	4.7	46	14.8	39	15.6	51	13.3
Grass Height (cm)			16	5.8			29	9.1	37	36.8	37	12.6
Shrubs[3]			4	3.5			5	8.8	4	4.2	1	1.6
Shrub Height (cm)			-[4]	-			54	23.0			76	15.9
Bare Ground	28	18.4	62	10.6	32	16.8	45	4.6	45	18.8	34	22.8
Leaf and Wood Debris	66	19.6	7	5.7	65	21.0	5	3.6	18	10.2	16	10.4
Species Richness	3		5		2		5		6		5	

[1] *Habitat 1=Tamarisk dominated, 2=Grassland with mixed shrubs, 3=Grassland devoid of tamarisk*

[2] *Grass and forb species in order of overall abundance: Alkali sacaton, Common Purslane (*Portulaca oleacea*), Kochia, Inland Saltgrass (*Distichlis spicata*), Galleta (*Hilaria jamesii*), Jimmy-weed (*Isocoma wrightii*)*

[3] *Shrub species in order of overall abundance: honey mesquite, Iodine Bush (*Allenrolfea occidentalis*) Tamarisk, seep willow.*

[4] *Data unavailable*

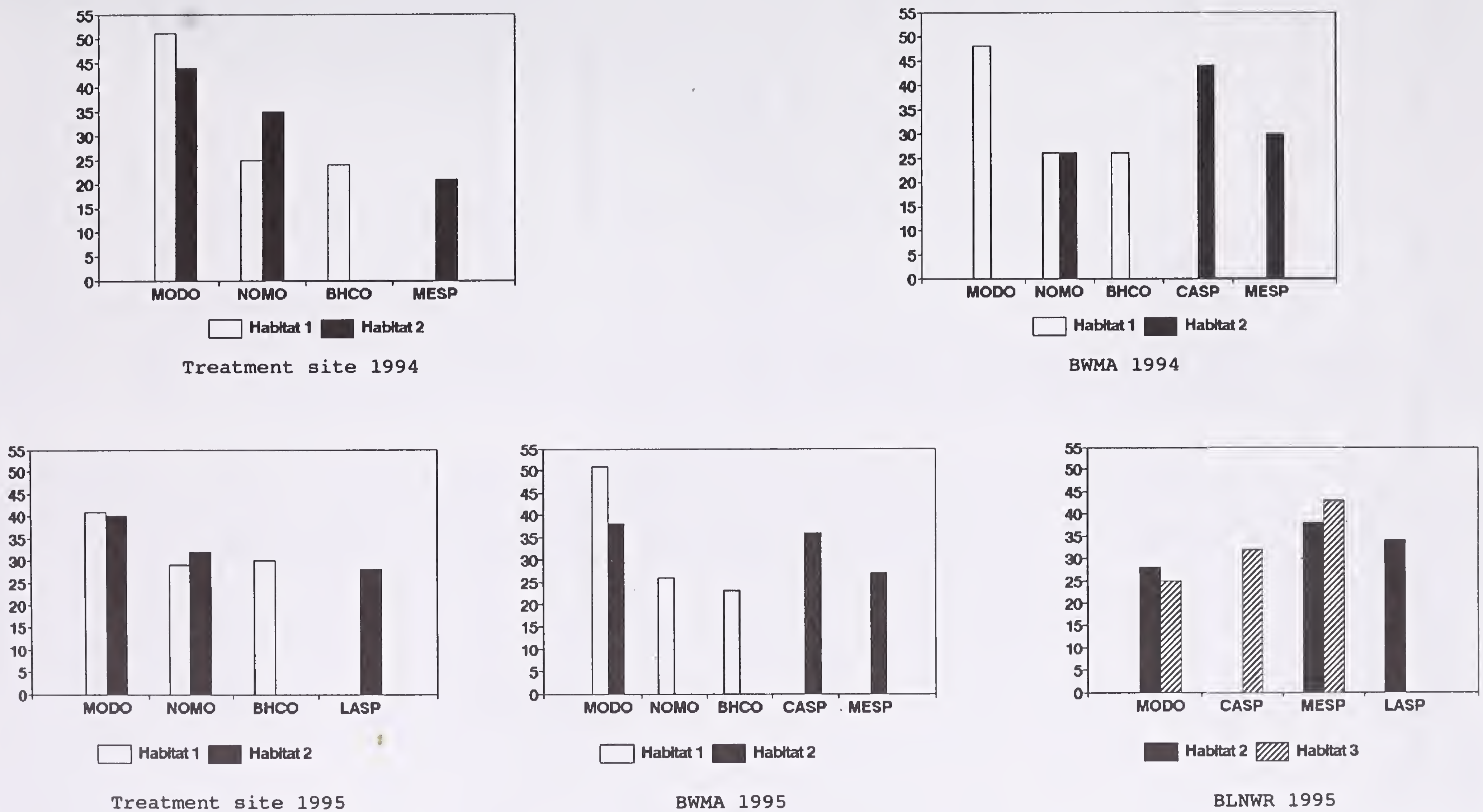


Figure 1. Dominant species for three sites by habitat in 1994 and 1995. Alpha codes: BHCO=Brown-headed Cowbird, CASP=Cassin's Sparrow, LASP=Lark Sparrow, MESP=Meadowlark spp, MODO=Mourning Dove, NOMO=Northern Mockingbird.

Table 3. Bird species mean abundance for three sites in summer 1994 (row top value) and 1995 (row bottom value), southeastern New Mexico.

	Treatment				BWMA				BLNWR[1]			
	Habitat 1[2]		Habitat 2		Habitat 1		Habitat 2		Habitat 2		Habitat 3	
Species	$\bar{x}$	*SD*	$\bar{x}$	*SD*	$\bar{x}$	*SD*	$\bar{x}$	*SD*	$\bar{x}$	*SD*	$\bar{x}$	*SD*
Mallard					0	0.0					-	-
Anas platyrhynchos					2	0.0					2	0.3
Northern Bobwhite							1	0.5				
Colinus virginianus							1	0.5				
Ring-necked Pheasant	2	0.5			2	0.7						
Phasianus colchicus	2	0.7			2	0.3						
Mourning Dove	40	6.4	25	2.1	52	4.8	12	1.3	-	-	-	-
Zenaida macroura	23	3.4	13	2.1	40	3.1	6	0.7	5	1.0	3	0.5
Yellow-billed Cuckoo	1	0.2			5	0.6						
Coccyzus americanus	0	0.0			4	0.3						
Greater Roadrunner	1	0.5			0	0.0			-	-		
Geococcyx americanus	0	0.0			2	0.3			1	0.0		
Common Nighthawk					1	0.0	2	0.4				
Chordeiles minor					0	0.0	1	0.0				
Ladder-backed Woodpecker			1	0.0			1	0.2				
Picoides scalaris			0				0	0.0				
Western Kingbird			3	0.8	8	2.6	12	1.2				
Tyrannus verticalis			6	0.2	6	1.7	9	2.0				
Ash-throated Flycatcher					2	0.4	2	0.2				
Myiarchus cinerascens					0	0.0	0	0.0				
Western Wood Pewee			1	0.2	0	0.0						
Contopus sordidulus			1	0.0	1	0.5						
Bewick's Wren			0	0.0	4	0.7						
Thyomanes bewickii			2	0.4	2	0.4						
Northern Mockingbird	24	2.1	20	0.9	19	0.6	19	0.6	-	-		
Mimus polyglottos	16	0.5	14	0.7	20	4.1	15	0.3	4	0.9		
Curve-billed Thrasher	1	0.0			3	0.5						
Toxostoma curvirostre	1	0.2			1	0.2						
Yellow-breasted Chat	1	0.0	1	0.0	6	1.0						
Icteria virens	1	0.2	0	0.0	6	1.3						
Blue Grosbeak	17	1.3	10	0.1	12	0.6	5	0.8	-	-		
Guiraca caerulea	16	1.8	8	1.5	14	2.0	3	0.3	4	1.0		
Cassin's Sparrow					2	0.0	33	3.9			-	-
Aimophilia cassinii					0	0.0	14	0.8			6	1.8
Rufous-sided Towhee	4	0.7			6	0.8						
Pipilo erythrophthalmus	3	0.5			7	1.1						
Lark Sparrow			11	2.0	1	0.0	7	1.8	-	-		
Chondestes grammacus			7	1.4	0	0.0	8	0.8	6	0.7		
Meadowlark spp.	1	0.0	12	1.9	2	0.2	18	2.2	-	-	-	-
Sturnella spp.	1	0.0	4	0.8	1	0.0	13	3.0	9	1.4	8	1.1
Brown-headed Cowbird	23	2.1	12	1.6	24	2.8	5	0.9	-	-	-	-
Molothrus ater	17	1.7	9	1.3	17	1.2	4	0.7	3	1.4	2	0.0
Northern Oriole					1	0.0	1	0.0				
Icterus galbula					0	0.0	1	0.0				
Total Mean Abundance	116		96		150		118		-		-	
	81		64		123		75		32		21	
Species Richness	11		10		17		14		-		-	
	8		9		15		11		7		5	

[1] *Only surveyed in 1995.*

[2] *Habitat 1=Tamarisk dominated, 2=Grassland with mixed shrubs, 3=Grassland devoid of tamarisk.*

Table 4. Results from analysis of variance site comparisons for bird mean abundance and species richness in Summer 1994 and 1995, southeastern New Mexico. *Indicates significant difference at 0.05 level.

Site comparison[1]	Variable	Habitat[2]	1994 p-value	1995 p-value
1 vs 2	Mean Abundance	Pooled	0.0180*	0.1289
		1	0.0163*	0.0330*
		2	0.0535	0.5393
	Species Richness	Pooled	0.0289*	0.0124*
		1	0.0877	0.0401*
		2	0.2347	0.6123
1 vs 3	Mean Abundance	Pooled	-[3]	0.0466*
		1	-	-
		2	-	0.0138*
	Species Richness	Pooled	-	0.0303*
		1	-	-
		2	-	0.1951
2 vs 3	Mean Abundance	Pooled	-	0.0026*
		1	-	-
		2	-	0.0050*
	Species Richness	Pooled	-	0.0001*
		1	-	-
		2	-	0.0864

[1] *Site 1=Treatment, 2=BWMA, 3=BLNWR*

[2] *Habitat 1=Tamarisk dominated (only at treatment site and BWMA), 2=Grassland with mixed shrubs, 3=Grassland devoid of tamarisk (only at BLNWR)*

[3] *Site 3 only sampled in 1995*

DISCUSSION

Anderson et al. (1977 and 1978) found negative relationships between species richness and tamarisk abundance on the lower Colorado River. Engel-Wilson and Ohmart (1978) found higher bird density and species diversity in cottonwood-willow than tamarisk along the lower Rio Grande. In contrast, Ellis (1995) reported no difference in species richness between tamarisk and cottonwood vegetation along the middle Rio Grande. Thompson et al. (1994) suggested that tamarisk and the exotic Russian olive (*Elaeagnus angustifolia*) in conjunction with native species may provide structure for Rio Grande avifauna that was historically supplied by cottonwood-willow communities.

Hunter et al. (1988) reported tamarisk habitats surpassed grassland/shrub habitats in overall species richness and densities on the Pecos River. Sparse, short honey mesquite habitat ranked lowest in importance to birds. Hildebrandt and Ohmart (1982) described open grassland habitats on the Pecos as supporting few birds. Our data support these findings for between site comparisons.

Overall, BLNWR had significantly fewer terrestrial birds than the other two sites (Tables 3 and 4). Only 23% and 32% of all species used for analyses occurred in the monotypic grassland and grassland/shrub habitats at BLNWR, respectively. No species was unique to the refuge. Species richness was not different between sites for grassland/shrub habitat, but BLNWR had fewer species when habitats were pooled. Differences were augmented because habitat 3 at BLNWR contained the fewest species. Habitat 3 was characterized as a monotypic grassland of alkali sacaton with minimal shrub composition (Table 2). We attribute the less rich and abundant terrestrial bird community at BLNWR to the lack of vegetational structure when compared to the other two sites. Wiens (1973) described grassland bird communities as consisting of few species, low abundance, and single species dominance, particularly at low rainfall sites. Cody (1985) also described similar grassland avifauna characteristics. We recognize many processes work towards the patterns observed in bird communities (Wiens 1989). However, when differences are as extreme as our data indicate a single factor explanation such as woodland plant density may be justified. Smith (1977) explained a lack of birds in dry forest compared to mesic forest in an Ozark watershed as a result of a moisture gradient. In contrast, Sabo and Holmes (1983) attributed observed differences in the bird communities in contrasting montane habitats to multiple factors including evolutionary and ecological pathways.

Factors which may have contributed to differences in bird community patterns between the treatment site and BWMA are more complex than woodland plant density. The two sites are separated by only five kilometers and are within a continuous strip of tamarisk extending along the river. Vegetation structure was not different between the two sites (p=0.4687 for habitat 1, p=0.5140 for habitat 2). Grazing is a possible factor; however, bird abundance and species richness were not different between the grazed site (treat-

ment) and non-grazed site (BWMA) in the grass/shrub habitat (Tables 2 and 3). This habitat was more susceptible to grazing when compared to tamarisk areas, which had little forage for cattle to influence. Our study was not designed to evaluate grazing impacts and, therefore, our assumptions are merely speculative. Taylor (1986) found a direct relationship between increased grazing and decreased bird abundance, shrub volume and shrub heights along the Blitzen River in Oregon. Other studies have reported similar results (Klebenow and Oakleaf 1984, Krueper 1992). Bock et al. (1992) reviewed available literature pertaining to grazing impacts on neotropical migratory birds in western North America. They determined that in Southwestern grassland habitat Northern Mockingbird and Lark Sparrow responded positively to grazing, Eastern and Western Meadowlarks responded negatively to heavy grazing, Cassin's Sparrow responded negatively to varied grazing intensity, and Mourning Dove and Brown-headed Cowbird had mixed or uncertain responses to grazing. No clear patterns in mean abundance for Northern Mockingbird and Lark Sparrow were present between sites in our study. Eastern and Western Meadowlarks appeared to be more abundant at the non-grazed sites especially in 1995. Cassin's Sparrows were markedly more abundant at the non-grazed sites. Mourning Dove and Brown-headed Cowbird showed no clear patterns (Table 3).

Factors contributing to higher bird abundance and species richness in the tamarisk habitat at BWMA may have included habitat juxtaposition and interspersion. A major disparity between the treatment site and BWMA was the latter contained a 0.3 km by 8.0 km mowed strip. The area was created to allow surface flow during high water periods. Vegetation consisted of perennial weeds and annual forbs. It paralleled the river at a distance approximately 1.0 km west. Between the floodway and river were dense tamarisk stands (habitat 1) and west of it were sparse tamarisk stands opening to grassland/shrub areas (habitat 2). This area probably provided many birds foraging habitat. The treatment site lacked an area comparable to the flood-way at BWMA.

The habitat mosaic at BWMA and the treatment site differed in other respects. Alfalfa fields bordering BWMA provided additional foraging habitat. Studies have indicated that riparian bird densities increase when nearby foraging habitat is present (Carothers et al. 1974, Conine et al. 1978, Anderson et al. 1984). Meyer (1995) discussed the positive influences of agricultural fields on riparian bird communities along the Rio Grande in southern New Mexico. At BWMA, honey mesquite areas were more extensive contributing an additional vegetational component to the habitat complex. In contrast, the treatment site's western bordering areas encompassed grazed pasture and human residences. These areas were less structurally diverse than the BWMA western border regions. Moreover, roads fragmented the treatment site extensively. Consequently, the area received heavier amounts of human activity including gas/oil extraction and off-road vehicle use.

Hunter et al. (1987) described five riparian bird species as declining in the Southwest except along the middle Pecos River where numbers were stable. The species were Harris' Hawk (*Parabuteo unicinctus*), Yellow-billed Cuckoo, Vermillion Flycatcher (*Pyrocephalus rubinus*), Summer Tanager (*Piranga ruba*), and Yellow-breasted Chat. These five species were present in the summer months in our study, but only Yellow-billed Cuckoo and Yellow-breasted Chat were abundant enough to include in analyses. Dense tamarisk stands next to the river appeared to be the most important habitat for these two species. Both species were commonly detected in tamarisk dominated areas, but rarely in grassland/shrub areas at BWMA (Table 3). The woodland dependent Rufous-sided Towhee (Ehrlich et al. 1988) was common in tamarisk dominated habitat at the treatment site and BWMA, but absent in grassland/shrub at all sites and monotypic grassland habitat at BLNWR (Table 3). Grassland/shrub and monotypic grassland habitats were most important to Cassin's and Lark Sparrows and Eastern and Western Meadowlarks (Fig. 1). These four species have affinity for open grassland habitat with scattered shrubs (Ehrlich et al. 1988).

CONCLUSIONS AND DESIRED FUTURE CONDITIONS

Our data indicate that floodplain grassland areas on the middle Pecos River are low in bird abundance and species richness when compared to tamarisk habitat. These areas are, however, impor-

tant to grassland birds including Cassin's and Lark Sparrows, and Eastern and Western Meadowlarks. Removing tamarisk from the Pecos River will provide these species with additional habitat. In contrast, we believe the vegetational structure provided by tamarisk benefits certain bird species. Yellow-billed Cuckoo, Yellow-breasted Chat, and Rufous-sided Towhee will lose essential habitat when tamarisk is removed. In order to prevent population declines for these species on the middle Pecos River the structure provided by tamarisk must be replaced. Establishment of native cottonwood/willow groves should be encouraged where soil and hydrologic conditions are favorable. Preferably, tamarisk removal will proceed at a rate that will leave sufficient structure for populations to persist.

LITERATURE CITED

Anderson, B.W.; Ohmart R.D. 1977. Vegetation structure and bird use in the lower Colorado River Valley pp. 23-34. In: Importance, preservation, and management of riparian habitat: symposium (proceedings), Johnson, R.R. and Jones, D.A. (tech. coords.) USDA For. Serv. Gen. Tech. Rep. RM-43. 217 pp.

Anderson, B.W.; Higgins, A; and Ohmart, R.D. 1977. Avian use of saltcedar communities in the lower Colorado River Valley pp. 128-136. In: Importance, preservation, and management of riparian habitat: symposium (proceedings), Johnson, R.R. and Jones, D.A. (tech. coords.). USDA For. Serv. Gen. Tech. Rep. RM-43. 217 pp.

Anderson, B.W.; Ohmart, R.D.; and Disano, J. 1978. Revegetating the riparian floodplain for wildlife. pp. 318-331 In: Strategies for protection and management of floodplain wetlands and other riparian ecosystems: symposium (proceedings) Johnson, R.R. and McCormick, J.F. (tech. coords.) USDA For. Serv., Gen. Tech. Rep. WO-12. 410 pp.

Anderson, B.W.; Ohmart, R.D. 1984. A vegetation management study for the enhancement of wildlife along the lower Colorado River. Comprehensive final Report submitted to U.S. Bureau of Reclamation. Boulder City, NV. 529 pp.

Bock, C.E.; Saab, V.A.; Rich, T.D.; and Dobkin, D.S. 1993. Effects of livestock grazing on neotropical migratory landbirds in western North America. pp. 296-309 In: Status and management of neotropical migratory birds: symposium (proceedings), Finch, D.M. and Stangel, P.W., (eds.). USDA For. Serv., Gen. Tech. Rep. RM-229. 422 pp.

Buckland, S.T.; Anderson, D.R.; Burnham, K.P.; and Laake, J.L. 1993. Distance sampling: estimating abundance of biological populations.Chapman and Hall, London. 446 pp.

Canfield, R.H. 1941. Application of line interception method in sampling range vegetation. J. Forestry 39: 388-394.

Carothers, S.W.; Johnson, R.R.; and Aitchison S.W. 1974. Population structure and social organization of southwestern riparian birds. Am. Zool. 14:97-108.

Cody, M.L. 1985. Habitat selection in grassland and open-country birds. pp. 191-226 In: Habitat selection in birds. M.L. Cody, Ed. Academic Press, New York. 558 pp.

Conine, K.H.; Anderson B.W.; Ohmart, R.D.; and Drake, J.F. 1978. Responses of riparian species to agricultural habitat conversions. pp. 248-262 In: Strategies for protection and management of floodplain wetlands and other riparian ecosystems: symposium (proceedings) Johnson, R.R. and McCormick, J.F. (tech. coords.) USDA For. Serv., Gen. Tech. Rep. WO-12. 410 pp.

Cottam, G.; Curtis, J.T. 1956. The use of distance measures in phytosociological sampling. Ecology 37: 451-460.

Dick-Peddie, W.A. 1993. New Mexico vegetation past, present, and future. University of New Mexico Press. Albuquerque, 244 pp.

Ehrlich, P.R.; Dobkin, D.S.; and Wheye, D. 1988. The birder's handbook: a field guide to the natural history of North American birds. Simon and Schuster, New York. 785 pp.

Ellis, L.M. 1995. Bird use of saltcedar and cottonwood vegetation in the middle Rio Grande Valley of New Mexico, U.S.A. J. of Arid Environ. 30: 339-349.

Engel-Wilson, R.W.; Ohmart R.D. 1978. Floral and attendant faunal changes on the lower Rio Grande between Fort Quitman and Presidio Texas. USDA, For. Serv. Gen. Tech. Rep. WO-12:139-147.

Farley, G.H.; Ellis, L.M.; Stuart, J.N.; and Scott, N.J., Jr. 1994. Avian species richness in different-aged stands of riparian forest along the Middle Rio

The influence of prehistoric Anasazi cobble-mulch agricultural features on northern Rio Grande landscapes

Richard D. Periman[1]

Abstract.—Research concerning ancient Pueblo Indian farming, specifically the innovation of cobble-mulch gardens, suggests a manipulation of the local environment on a landscape level that helped create existing ecosystems. This agricultural technology, which consisted of a protective layer of gravel covering the productive soil, trapped seasonal runoff moisture in field areas, retained it, and guarded against evaporation. These water trapping features are usually found on terraces and slopes above riparian areas. The effect of this lithic-mulch technology on available water, drainage patterns, and general system dynamics is explored.

INTRODUCTION

Anthropogenic, or humanly created, landscapes cover the earth. Using differing technologies, cultures have dramatically altered riparian areas throughout history. Water being by biological necessity the main attraction, riparian areas abound with game and plants used for food, medicine, and shelter. Stream side areas and the resources associated with them have been utilized by people across North America for at least the past 12,000 years.

Studying the dynamics involved in the development of specific human landscapes is essential to understanding the active human role in the evolution of North American ecosystems. My purpose here is briefly to discuss a system of land and water use employed by the Rio Grande Anasazi that contributed to the cumulative development of contemporary landscapes, involving possible lasting effects to riparian areas. The cumulative effect of the ancient farming techniques, including cobble-mulch gardens, may have been as influential in shaping existing landscapes as modern riparian usage. By clearing land for agriculture, constructing fields and water control structures, collecting wood for fuel and construction, and asserting selective pressures on local vegetation and animal populations, the Anasazi helped to create today's ecosystem conditions. As a result, these cumulative anthropogenic landscapes include lower stream channels and riparian areas, various aspects of alluvial terraces, talus slopes, and mesas. The landscapes and ecosystems we presently observe in many northern Rio Grande tributary valleys were altered by a pattern of prehistoric and historic human manipulation, extensive use, and abandonment.

COBBLE MULCH AS AN AGRICULTURAL TECHNIQUE

Gardens constructed with surface mulches that utilized pebbles, cobbles, and other lithic materials, were uniquely suited to the constraints of dry land

[1]*Research Archaeologist, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Cultural Heritage Research Work Unit, located in Albuquerque, NM.*

environments. Use of cobble-mulch augments, traps, and retains available runoff moisture, elevates nighttime temperatures, and decreases soil erosion. Placement of lithic material on the surface elevates soil moisture retention by increasing infiltration and reducing the evaporative loss of water from wind and sun. By controlling weeds and raising soil temperature, mulching advances germination, growth, and maturation of crops (Lightfoot 1994:172). Stone mulch protects the soil surface from raindrop impact and runoff, further curtailing erosion, and inhibits salinization as the evaporation of salt-laden water at the soil surface is dramatically reduced (Lightfoot 1994:172). Lithic mulch also contributes to a better-distributed, deeper root system, improving drought tolerance.

Cobble-mulch distribution and history

Cobble-mulch agricultural methods have been used for more than two thousand years in both the Old World and the New World. The most ancient lithic-mulch plots are associated with ancient Nabatean sites in the Negev of southern Israel, where thousands of stone features were used between 200 B.C. and A.D. 600 (Kedar 1957; Lightfoot 1994; Issar 1995). In Italy and other regions of the Mediterranean, Roman agriculturalists produced grapes and olives using cobble mounds between 100 B.C. and A.D. 400 (Lightfoot 1994). Cobble-mulch features were used on the arid island of Lanzarote in the Canary Islands, near river channels in the Lanzhou area of central China, in the Atacama Desert of Peru, in northwestern Argentina, and in New Zealand (Lightfoot 1994).

In the American southwest, the Hohokam used as many as 42,000 rock mounds to grow agave in the Phoenix-Tucson region of southern Arizona between A.D. 850 and A.D. 1300 (Fish et al.1990; Lightfoot 1994). Ridges of ash, cinder mounds, and rock piles, collectively covering an area greater than four hectares, were used by the Sinagua people between A.D. 1150 and A.D. 1250 for growing crops in the volcanic Sunset Crater region northeast of Flagstaff, Arizona (Berlin et al. 1990; Lightfoot 1994).

Northern New Mexico also contains hundreds of hectares of land altered by cobble-mulch gardens covering terrace and mesa tops around Anasazi pueblo sites, most built and abandoned in the century between 1350 and 1450 (Cordell 1984; Anschuetz [In press b.]; Lightfoot 1993 and 1994). Such gardens may be found in the lower Chama, Rio del Oso, and Ojo Caliente valleys north of Santa Fe, though use and distribution may have been limited. Once believed to have been the stone foundations of pueblo dwellings, the function of these structures as gardens has been confirmed by the repeated recovery of maize and native cotton pollen in soil samples and from the discovery of stone cultivation tools on pebble-mulch gardens in the Galisteo Basin and the Rio del Oso (Lightfoot 1993 and 1994; Anchuetz [In press b.]).

Puebloan agriculture and cobble-mulch gardens

In much of the Anasazi Southwest after A.D. 900, domestic crops provided most of the nutritional requirements of the people. Considerable labor was expended to ensure agricultural success (Cordell, 1984). Prehistoric Puebloans manipulated their environments to produce corn and other crops within a wide variety of challenging settings and climatic conditions. Through a combination of strategies involving seed selection, fallowing fields, planting in different locations, staggering the time of plantings, and maintaining separate plantings of different corn and bean varieties, the problems of deficient moisture and short growing seasons were diminished (Lightfoot 1993).

The settlement of the upper Rio Grande region by Anasazi peoples appears to have occurred approximately between A.D. 1200 and 1500 (Cordell 1984; Anschuetz [in press b.]). Greater population densities, and increased social and economic pressures, were among the forces that may have pushed groups of ancient farmers into upland areas during the later part of the twelfth century A.D. By the late 1200s, Anasazi peoples had settled many Rio Grande tributary drainages (Cordell 1984). The Galisteo basin, Rio Chama, and Rio del Oso were inhabited and used to varying degrees during this time, although the sizes of pueblos and populations remained small (Lightfoot 1993; Anschuetz [In press b.]). By the early 1300s, referred to as the Pueblo IV period, the environmental conditions of the San Juan Basin in the Four Corners region had become increasingly arid and less predictable. The northern Rio Grande

and its tributaries represented a favorable alternative for agriculture and settlement (Cordell 1984; Fish et al. 1994).

Coinciding with the fourteenth century abandonments in the Four Corners region, increased immigration of Anasazi people to the northern Rio Grande appears to have taken place. The archaeological record of this period suggests that small villages were abandoned as people aggregated to larger settlements (Cordell 1984; Fish et al.1994). These agricultural Puebloan groups settled many of the narrow drainage systems in the upper reaches of the Rio Grande, as demonstrated by the construction of large pueblo villages with sustained year-round occupation. Substantial multistoried communities were established throughout much of the northern Rio Grande by the first half of the fourteenth century (cf. Wendorf and Reed 1955 in Cordell 1984; Anschuetz [in press b.]). This dramatic change in population distribution is exemplified in the Galisteo Basin where eight major Puebloan towns were established by 1350, each containing 1,000 to 3,000 rooms (Lightfoot 1993).

This apparent explosion in population and building, from the early fourteenth century into the early fifteenth, required greatly intensified and expanded agricultural production to support it. Subsistence risk was spread to ensure acceptable levels of harvest by using a variety of agricultural technologies, each adapted to the conditions of specific micro-environments or situations. Puebloan people in the northern Rio Grande during the fourteenth and fifteenth centuries utilized flood water irrigation, diversion dams, head gates, canals and ditches, in conjunction with floodplain fields, runoff fields, check dams, terraces, bordered gardens, and pebble-mulch gardens. With few exceptions these last structures were fabricated from in situ lithic materials, usually with stones or gravel found on or immediately below the surface of the ground. Stones were most frequently piled as mounds or in solid layers. Anasazi farmers made adjustments for seasonal variation by diversifying the location of fields (Woolsey 1980; Lightfoot 1993). The systematic use of such a variety of water harvesting and conservation techniques ensured that even marginally available water was not wasted. All these methods, including cobble-mulch gardening, allowed ancient farmers to expand arable land into areas previously considered less suitable for agriculture, and buffer their crops against inevitable drought (Anshuetz [In press a.]; Lightfoot 1993 and 1994).

STRUCTURE AND FUNCTION OF COBBLE-MULCH GARDENS

In 1994, White, Loftin, and Aguilar conducted a systematic analysis of cobble gardens located on Ojo Caliente river terraces, providing a vital understanding of the structure and general ecology of these agricultural features. Their work concluded that the gardens were usually constructed on Pleistocene fluvial cobble terraces, with sandy A horizons. This aspect is important, ". . .because (1) it would allow rapid infiltration of water and (2) a larger proportion of soil water can be extracted from sandy soils than from soils with greater clay content. Thus, rain could rapidly infiltrate and a high proportion is available to plants" (White et al. 1995: 16).

The researchers found that all of the cobble gardens tested were constructed on terraces with argillic B soil horizons. These argillic horizons function to retain water within the upper soil, thereby acting as a barrier to moisture loss. A similar effect occurs with the presence of a caliche horizon (White et al. 1995:17). Studies of ancient terrace farming features in the Mimbres area of New Mexico also suggest that a layer of impermeable caliche retains enough moisture for successful farming in arid conditions when using such techniques (Sandor et al. 1990).

Cobble-mulch gardens would have produced a more favorable agricultural environment for prehistoric farmers, and continue to support a greater cover of native plants on the garden plots than on surrounding areas (White et al. 1995:17). The presence of cryptogamic crusts verifies greater water retention (White et al. 1995), and according to Loftin and White (personal conversation, 1995) appears to contribute significant amounts of nitrogen to the soil. This concentration is highest in the upper horizons within the gardens, and would have acted to replenish soil fertility during fallow periods.

Currently, old cobble-mulch gardens continue to stabilize soil surfaces and protect the cryptogamic

crusts and other plants from root damage caused by grazing animals. "As a result, cobble mulch gardens presently function as islands of refuge for local vegetation (and perhaps associated fauna). Such refugia act as a source of seeds and genetic material to enhance the present rate of recovery of disturbed grasslands" (White et al. 1995:19).

The placement of cobble fields on slopes and terraces above drainages and riparian areas likely made the plots less susceptible to frost due to cold drainage qualities (Sandor et al. 1990; Anschuetz [in press b.]; Lightfoot 1994). Hydrologists have shown that small watersheds have a greater frequency of runoff events and increased runoff yield per unit area in arid regions than one would assume (Petersen and Mattews 1987:12-13; Lighfoot 1994). The runoff farming method used in the Negev Desert of Israel is a well-documented example of this hydrologic knowledge used in ancient agriculture (Evenari et al. 1961; Issar 1995).

ANTHROPOGENIC LANDSCAPES AND RIPARIAN AREAS

Within a landscape context, the structural and functional qualities of cobble-mulch gardens should be viewed as integral components within a larger system of water and land manipulation. As noted above, prehistoric agriculture had significant long-term impacts on the landscapes and ecosystems of North America (Denevan 1992; Doolittle 1992; Whitmore and Turner 1992). To truly appreciate this scale of impact and change, the entire system of land use needs to be examined.

The approach in this study employs the concept that the distribution of archaeological artifacts and features in relation to elements of the landscape provides insight into past social and economic systems. By focusing on land use, potentially synergistic connections among ecosystems, landscape physiography, and the spatial aspects of human environmental manipulation may be investigated. This archaeological inquiry into past land use through a landscape perspective combines the use of regional geomorphology with study of taphonomy, formation process, and ethnoarchaeology (Rossignol 1992:4). Past cultural landscapes cannot be observed or described directly, as their composition, structure and development must be reconstructed from available paleoecological and archaeological evidence. The ecology, function, and maintenance of a cultural landscape through time must be inferred through such reconstructions (Birks et al. 1988). As Crumley and Marquardt have noted, "Landscapes are real-world phenomena. In interacting with their physical environments, people project culture onto nature" (1990:73).

The overall human impact on an ecosystem is interrupted by periods of reversal and a degree of ecological rehabilitation as systems fail, populations decline, and habitats are abandoned. Environmental impacts may be constructive, benign, or degenerative, but change is continual, occurs at variable rates, and proceeds in different directions. Even mild impacts and slow changes accumulate, and long-term effects can be dramatic (Denevan 1992:381).

The Rio del Oso drainage, a tributary of the Rio Chama, is a compelling example of a landscape altered by Anasazi agricultural practices. From 1992 through 1994, Kurt Anschuetz, with the University of Michigan Museum of Anthropology, conducted extensive study of the Rio del Oso, showing that this tributary drainage of the Rio Grande was densely settled by Pueblo Indian groups between ca. 1200 and 1500. The team recorded 271 archaeological sites, ranging in age from the late Archaic period (before A.D. 400) to the middle of the nineteenth century (Anschuetz [in press a. and b.]).

Analysis of the archaeological record suggests that the Rio del Oso valley was most intensively occupied during the thirteenth and fourteenth centuries. Anschuetz's survey team found Pleistocene terraces associated with five prominent mesas located on the north side of the valley, covered with hundreds of technologically diverse prehistoric agricultural features. Opposite the mesas and fields are the ruins of four aggregated multi-storied pueblo villages (Ku, Te'ewi, Pesedeuinge and Maestas pueblos). Few agricultural features have been found on the south side of the valley, perhaps due to poor soils and lack of adequate solar exposure (Anschuetz [in press a. and b.]). It appears that between 1450 and 1500, the valley was essentially abandoned with only periodic farming, perhaps when conditions were favorable.

I have chosen to view the past of the Rio del Oso area as a series of temporally grouped anthropogenic landscape layers, rather than analyzing individual sites. Placing the Anasazi occupation of A.D. 1200 to A.D. 1500 within a tangible temporal context is important. Thousands of years of hunter gatherer land use likely had a significant, though different, impact on this landscape from that created by Puebloan peoples. Each period of land use in the valley contains a unique set of landscape altering dynamics, and the preceding occupations provided a base for the next stage. In essence, this landscape has passed through a process of differentially intensified domestications.

The reconfigured landscapes resulted from combined and cumulative settlement, and were not just the result of one culture's agroecological landscape replacing another's (Doolittle 1992). These dynamic historical processes created "hybrid" landscapes (Whitmore and Turner 1992). The Puebloans landscape was not replaced by a Spanish ranching landscape created by livestock grazing and road building; rather, the latter system was built upon the former. A landscape ecosystem never returned to its "natural" condition, but it was transformed by subsequent human processes. Anthropogenic transformation of the land took place as people

> "...engineered nature into regional mosaics comprised of diverse systems of cultivation which contributed to extensive land modification and conversion. The particular systems and the landscapes in which they were imbedded were the result of real and perceived needs in the context of the cultural and environmental constraints and opportunities" (Whitmore and Turner 1992:419).

Puebloan cobble-mulch gardens and the water harvesting features associated with them would have augmented the effects created by clearing the land for agriculture (fig. 1). Runoff was controlled, directed, and then retained within the soil of the garden plots. The plots received direct rain, runoff moisture, and snowmelt before it could flow off the mesas and mid level terraces to the riparian areas below. The stone agricultural features essentially functioned as reservoirs. Less water would subsequently have reached riparian areas, and this in turn would have affected vegetation as well as the hydrological dynamics of the system (fig.2-3). By controlling runoff and erosion, the physiography of the landscape was likely maintained and

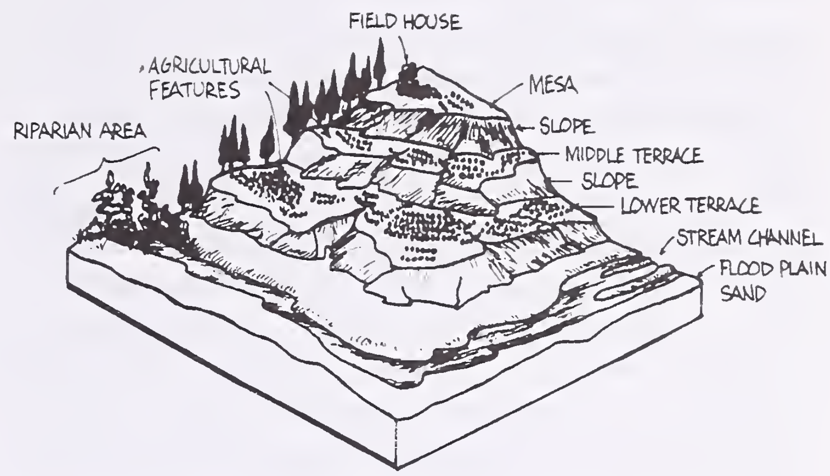


Figure 1. Landscape with cobble-mulch gardens.

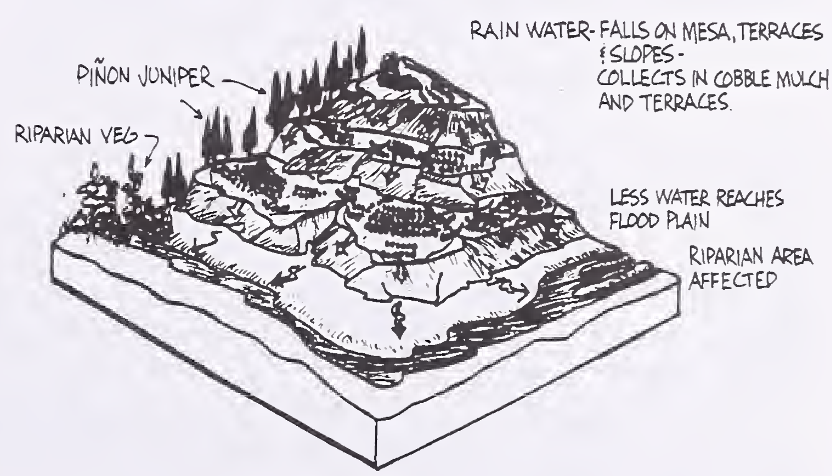


Figure 2. Runoff and cobble-mulch landscape.

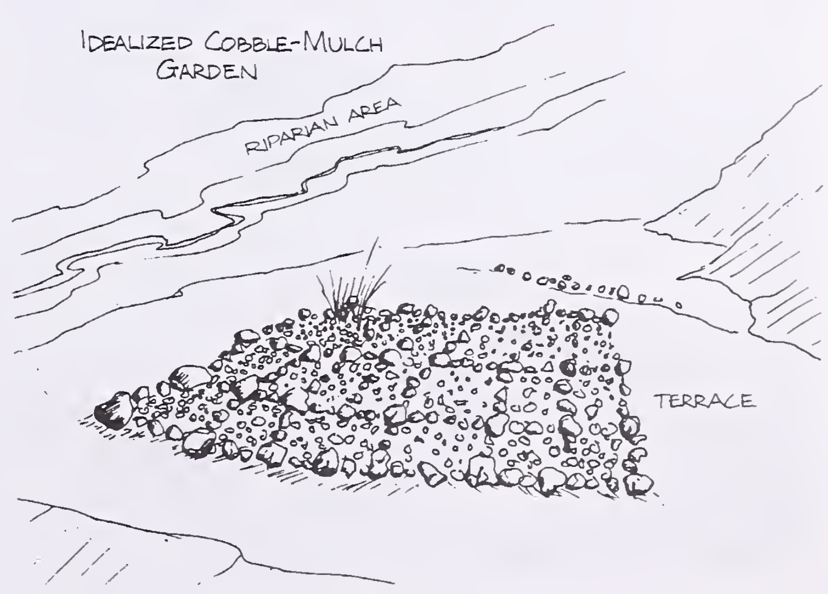


Figure 3. Reconstructed cobble-mulch plot.

sediment loading decreased. Although Anasazi crops no longer grow on the cobble-mulch fields, the water conserving mulch remains in place, stimulating more vigorous plant growth in the native short grasses on the gardens rather than off the gardens on non-mulched soil. This difference in plant density and vigor is remarkably visible in color infrared photographs of the Galisteo Basin taken by NASA's Stennis Space Center in September 1987. Through subsequent analysis of the photographs and follow up field surveys, Lightfoot was able to identify 96 previously unrecorded cobble-mulch gardens (Lightfoot 1993:116).

Research conducted by White and his colleagues supports the premise that these remnant agricultural landscape features persist in affecting ecosystems hundreds of years after abandonment (White et al. 1995). If this idea of continuing influence on the landscape is extended, a pattern of cumulative or increased ecological effect may be discerned (fig. 4). Considering that 50% of the total terrace area along the Rio Ojo Caliente is covered with cobble-mulch gardens and other agricultural features (White and Loftin, personal conversation, 1995), the overall influence of the anthropogenic landscape components becomes significant.

CONCLUSION

Ancient agricultural landscapes contain an abundance of evidence relating to the development and adaptation of agricultural systems, specific crop and soil management techniques, and the effects of agricultural land use on the physical environment. The archaeological record provides a necessary long-term view of land use, which is crucial to the development of sustainable agricul-

Figure 4. Agricultural landscape areas in the Rio del Oso.

tural systems that are productive and protective of soil and other natural resources (Brooks and Johannes 1990; Sandor et al. 1990).

Ancient peoples resourcefully and creatively adapted to environmental, climatic, and cultural challenges throughout their resilient 12,000 + year tenure on this continent. This intimate relationship with the landscape has played a vital and dynamic role in the evolution of ecosystems throughout the hemisphere. Future research will include a simulated reconstructive modeling of the Rio del Oso landscape, built upon data gained from a cross-sectional series of pollen and micro-charcoal cores. By studying ancient agricultural landscapes including cobble-mulch gardens, and through subsequent research of other landscape-shaping anthropogenic systems, we will be better able to understand this interaction and its continuing effects on today's ecosystems.

ACKNOWLEDGMENTS

I would like to thank Kurt Anschuetz of the University of Michigan Museum of Anthropology, for the generous contribution of his personal time in providing me with a tour of the archaeological landscape of the Rio del Oso. The use of his research and manuscripts for reference also is highly appreciated. I thank Joseph Tainter and Carol Raish for their helpful and substantive comments and suggestions. Joyce Patterson, illustrator for Rocky Mountain Station, provided valuable assistance with the slides and lettering for the illustrations.

REFERENCES

Anschuetz, K.F. [In press]. Saving a rainy day: The integration of diverse agricultural technologies to harvest and conserve water in the Lower Rio Chama Valley, New Mexico. In: Toll, H. Wolcott, ed. Proceedings of the New Mexico Archaeological Council Agricultural Symposium: recent work, new findings, and traditional practices in the agriculture of the Northern Southwest, 1993. Albuquerque: New Mexico Archaeological Council.

Anschuetz, K.F. [In press]. Earning a living in the cool high desert: Transformations of the Northern Rio Grande landscape by Anasazi farmers to harvest and conserve water. In: Redman, Charles L.; James, Steven R.; Fish, Paul R.; and Roberts, Daniel, eds., Human impact on the environment: an archaeological perspective. Tempe, AZ: Arizona State University.

Berlin, G.L.; Salas, D.E.; Geib, P.R. 1990. A prehistoric Sinagua agricultural site in the ashfall zone of Sunset Crater, Arizona. Journal of Field Archaeology. 17: 1-16.

Birks, H.J.B. 1988. Introduction. In: Birks, H.H.; Birks, H.J.B.; Kaland, P.E.; Moe, D., eds., The cultural landscape - past present and future. Cambridge: Cambridge University Press: 7-10.

Brooks, R.R.; Johannes, D. 1990. Phytoarchaeology. In: Dudley, T.R., ed. Historical, ethno- & economic botany series. Vol 3. Portland, OR: Dioscorides Press: 224 p.

Cordell, L.S. 1984. Prehistory of the Southwest. New York: Academic Press: 409 p.

Cordell, L.S. 1989. Northern and central Rio Grande. In: Cordell, L.S.; Gumerman, G.J., eds. Dynamics of Southwest Prehistory. Washington: Smithsonian Institution Press: 293-335.

Crumley, C.L.; Marquardt, W.H. 1990. Landscape: a unified concept in regional analysis. In: Allen, K.M.S; Green, S.W; Zubrow, E.B.W., eds. Interpreting space: GIS and archaeology. London: Taylor and Francis: 73-79.

Denevan, W.M. 1992. The pristine myth: The landscape of the Americas in 1492. Annals of the Association of American Geographers. 82(3): 369-385.

Doolittle, W.E. 1992. Agriculture in North America on the eve of contact: A reassessment. Annals of the Association of American Geographers. 82(3): 386-401.

Evenari, M.; Shannan, L.; Tadmor, N.; Aharoni Y. 1961. Ancient agriculture in the Negev. Science. 133: 979-996.

Fish, P.R.; Fish, S.K.; Gumerman, G.J.; Reid, J.J. 1994. Toward an explanation for southwestern "abandonments". In: Gumerman, G.J., ed. Themes in southwest prehistory. Santa Fe: School of American Research Press: 135-163.

Fish, S.K.; Fish, P.R.; Madsen, J. 1990. Sedentism and settlement mobility in the Tucson Basin Prior to A.D. 1000. In: Minnis, P.; Redman, C., eds. Perspectives on southwestern prehistory. Denver: Westview Press: 76-91.

Issar, A.S. 1995. Climatic change and the history of the Middle East. American Scientist. 83(4): 350-356.

Kedar, Y. 1957. Water and soil from the desert: some ancient agricultural achievements in the central Negev. Geographical Journal. 123:179-187.

Lightfoot, D.R. 1993. The cultural ecology of Puebloan pebble mulch. Human Ecology. 21: 115-143.

Lightfoot, D.R. 1994. Morphology and Ecology of Lithic-Mulch Agriculture. The Geographical Review. 84(2): 172-185.

Petersen, L.P.; Mattews, M.H. 1987. Man's impact on the landscape: a prehistoric example from the Dolores River Anasazi, Southwestern Colorado. Journal of the West. 26: 4-16.

Rossignol, J. 1992. Concepts, methods, and theory building: a landscape approach. In: Rossignol, J.; Wandsnider, L., eds. Space, time, and archaeological landscapes. New York: Plenum Press: 3-16.

Sandor, J.A.; Gersper, P.L.; Hawley, J.W. 1990. Prehistoric agricultural terraces and soils in the Mimbres area, New Mexico. World Archaeology. 22: 70-86.

White, C.S.; Loftin, S.R.; Aguilar, S.L. 1995. Final project report, ecology of cobble mulch gardens: structures for modification of soil moisture dynamics. Technical Report, Department of Biology, University of New Mexico and Albuquerque, NM: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest and Range Experiment Station. 20 p.

Whitmore, T.M.; Turner II, B.L. 1990. Landscapes of cultivation in Mesoamerica on the eve of the conquest. Annals of the Association of American Geographers. 82(3): 402-425.

Woosley, A.I. 1980. Agricultural Diversity in the Prehistoric Southwest. Kiva. 45: 317-335.

Historic land use and grazing patterns in northern New Mexico

Carol Raish[1]

Abstract.—The entrance of the Spanish into what is now New Mexico in the 1500s permanently altered aboriginal land use and subsistence patterns by the introduction of domesticated animals such as horses, cattle, sheep, goats, and pigs. During the Spanish Colonial and Mexican periods, both the Puebloan groups and the Hispanic settlers practiced mixed farming featuring small numbers of livestock pastured in communal grazing areas. After New Mexico became a United States Territory, large-scale ranching ventures also developed in the area. The rapid rise in stock numbers associated with the commercial ranching ventures, combined with 250 years of grazing around the existing small communities, led to degradation of land and water resources both in the uplands and in riparian areas. Large-scale efforts to reduce stocking and restore degraded lands have been undertaken by the federal government since the early 1900s. Yet grazing on federal lands remains a topic of controversy and debate, as well as an important aspect of the lifeway of the small Hispanic communities of the region. If the traditional lifeways of these communities are to survive, means must be found to balance the goals of ecosystem restoration with the stock raising needs of the small villages.

INTRODUCTION

In order to understand the complex issues surrounding livestock grazing on federal lands in northern New Mexico, it is necessary to understand the historical background of American Indian, Hispano, and Anglo-American patterns of subsistence and land use. To a very real extent, the cultural values and traditions of these groups are rooted in and developed from the subsistence practices of the past. If cultural diversity and intergroup tolerance are to be encouraged, an understanding of the roots of these cultural differences must be fostered.

This study focuses on a review of the subsistence practices of the rural Hispano villagers from 1598 to the present. It explores the effect of the conversion of community grazing lands to National Forest lands in the twentieth century on rural Hispano economics. Ongoing problems between the Hispano villagers and the Forest Service over grazing and other forest uses, which occasioned violent protest in the late 1960s, are examined in terms of present-day efforts at finding appropriate solutions.

THE SPANISH COLONIAL PERIOD

When the Spaniards arrived in Mexico in 1519, they set in motion not only the political conquest of North America but also the biological conquest of the continent. With the introduction of their domesticated plants and animals, they forever altered the flora, fauna, and landscape of the continent (Crosby 1972; Melville 1994). This conquest was effectively extended into what is now New Mexico with colonization of the region in

[1] *Research Social Scientist, Cultural Heritage Research Work Unit, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, located in Albuquerque, NM.*

1598 by Juan de Oñate. He brought with him 400 soldiers, colonists, friars, and Mexican Indian servants. In addition to these two-legged colonists, his four-legged colonists included cattle, goats, sheep, and horses (Hammond and Rey 1953(1):215, 390; Baxter 1987:4). Patterns of conflicting resource use in the Rio Grande Basin began in this earliest period of European colonization. The Spanish brought new technologies, subsistence strategies, and domesticates into the valley and introduced them into the existing native agricultural system. The colonists altered native farming practices by redirecting the agricultural emphasis away from extensive floodwater farming using water control and soil retention techniques to a reliance on intensive irrigation agriculture from major water-courses (Earls 1985:179-181; Wozniak 1995). Though riverine areas had always been favored farming and settlement locations, they became even more intensively utilized after European occupation.

Throughout the 1600s, Pueblo Indian populations declined primarily as a result of introduced diseases and famine caused by a series of severe droughts and destruction of food stores by raids from nomadic Indian groups. As the native population declined, the tribute and labor requirements of the colonists became more onerous. These conditions, along with forced relocations and missionization, led to the Pueblo Revolt of 1680. During this rebellion, the Spanish, or Hispanos, were forced out of the Rio Grande for 12 years. They returned in the period from 1692-1696 when Diego de Vargas initiated and completed the reconquest of New Mexico for the Crown.

From the recolonization of the reconquest, Hispano populations rose throughout the 1700s to approximately 25,000 by the latter part of the century. Even so, the significant population declines of the Puebloan groups left sufficient available land for both groups to survive as irrigation agriculturalists and stock raisers along the main waterways and their tributaries (Simmons 1979:182). During both the Spanish Colonial and Mexican periods, land use and ownership were confirmed by land grants from the Spanish Crown or Mexican government after independence. Land grants were of several types, with community grants, given to a group of settlers in common, of particular interest to this study (Harper et al. 1943:18-19; Eastman et al. 1971:4). The Spanish grants averaged 64,000 acres in size while some of the later Mexican grants were considerably larger (Eastman and Gray 1987). Within community grants, settlers received individually owned building sites in the village proper and agricultural plots of irrigated land near the ditch or stream. The irrigated plots were often quite small, averaging from 5-10 acres (Van Ness 1987:172). They also tended to grow smaller as they were divided for purposes of inheritance. The villagers also used or owned in common the village grazing lands, timber lands, and community pastures (Eastman et al. 1971:4). The fact that groups of kinsmen often tilled their fields cooperatively and herded their animals together assisted them in managing the small-sized, scattered plots.

Throughout the Spanish and Mexican periods, a subsistence, agro-pastoral economy based in small, scattered villages prevailed along the Rio Grande and its tributaries such as the Rio Chama. Information on the community of Cañones (Van Ness 1987) provides a good description of the importance of stock raising to the Hispano villagers and of its integration into the agro-pastoral system. Both animal and plant production were joined together in a true mixed farming system. The most important stock for food were sheep and goats, with small stock outnumbering cattle by as much as twenty to one. Average households probably owned from 50 to 100 head of all types of stock, with only the wealthiest of the community having larger herds. Livestock were used to plow the fields, to thresh the grain, to transport the produce, and to manure the fields. The farming side of the economy provided winter fodder and stubble grazing for the animals in the cleared fields. The community stock, individually owned but cooperatively grazed, were moved into the higher elevation pastures during the spring and summer and returned to the village after the harvest to graze and manure the stubble fields (Van Ness 1987:188-191).

The basic goal of the village economy was production for local subsistence, not for competition in a commercial market. During the 1700s and the earlier portion of the 1800s, nearby markets were limited and ready transportation to more distant markets was non-existent. In addition, raids by nomadic groups severely limited range

expansion. Even with the relatively small numbers of stock produced by the subsistence economy, however, concentration of the animals near the villages produced some areas of overgrazing in the Rio Grande Valley, in wetlands near communities, and in nearby upland grazing areas (cf.Baxter 1987:23; Elson 1992; Scurlock 1995a:4). Traditional grazing practices offered little respite for the land, but herd sizes were small and the land base was large. Herders had little trouble finding new and better pastures for their animals (Rothman 1989:196-197). Thus, relatively small populations of both humans and animals were able to utilize the resources of the Basin in a successful manner over the long time span of the Spanish Colonial period.

THE MEXICAN PERIOD

Overgrazing in favored areas intensified during the Mexican period from 1821-1846 as commercial production of sheep began to increase substantially (Scurlock 1995a:4). Even in 1802, during the Late Colonial period, there were sufficient sheep for local consumption and for traders to market ca. 26,000 annually in the southern markets. Throughout the Spanish and Mexican periods, external commerce depended on caravans from Santa Fe to El Paso and points further south, primarily Chihuahua and Durango. By 1827, the livestock industry in New Mexico tallied almost one quarter million sheep and goats but only about 5000 cattle and 3000 horses and mules. During this period, the developing commercial sheep operations began to seek additional pasture lands to the east and in the plains beyond the Sandia and Manzano Mountains, grazing these areas for the first time (cf. Baxter 1987:69,90,92-95). By the end of the Mexican period, serious range deterioration was noted by American military personnel entering the Rio Grande Valley (cf. Elson 1992). Areas of poor range condtion occurred from Santo Domingo to Taos in the north and from Cochiti to Socorro in the south. In addition, the middle Rio Puerco was already noted for poor forage conditions as were the Navajo lands higher up the Rio Puerco drainage. Thus, prior to Anglo-American occupation, areas along major drainages near settlements and in the Navajo lands were suffering the effects of overgrazing (cf. Elson 1992; Scurlock 1995b:2).

THE ANGLO-AMERICAN PERIOD

Conquest of the region by the United States in the Mexican War ultimately led to serious changes in both land ownership and patterns of range use in New Mexico. Differences in American and Spanish land laws, as well as unscrupulous land speculation, eventually resulted in the loss of over 80% of the Spanish and Mexican land grants to their original owners (Harper et al. 1943:17-21; Eastman et al. 1971:4-5). The Treaty of Guadalupe Hidalgo guaranteed the property rights of all former Mexican citizens living within the Territory, and Congress designated itself the body to rule on the validity of land claims. Unfortunately, the adjudication process was fraught with problems. Grant boundaries were often vague, many of the original titles had been lost, and common ownership of pasture and woodlands was at odds with established American concepts of private ownership. Thus, many grants were never confirmed and ended up in the public domain (Eastman et al. 1971:5). Often, house lands and small irrigated plots were confirmed, but the community pasture and woodlands, essential to the survival of mixed farmers, were not. In addition, much land that was confirmed was lost through inability to pay taxes under the American system of monetary tax payments. Also under the American system, common lands could be sold without consent of all owners (de Buys 1985:178-179).

Other forces of change were also at work during this time with the economy changing from a subsistence to a commercial base in at least some critical areas. The population of the territory grew tremendously during this period fueled by in-migration from the United States. Many of these immigrants brought substantial capital for investment in large-scale operations and a nineteenth-century, entreprenurial resource utilization ethic focused on maximum harvest for maximum profit (Scurlock 1995b:2). To add to the climate of growth and development, federal and territorial legislation, initially designed to foster primarily Anglo-American development, promoted intensive use of the environment (Scurlock 1995b:2). These factors, combined with expanding markets opened by the entrance of the railroad into the Rio Grande Valley in 1880 and the final subjugation of the nomadic

Indian groups, led to rapid increases in large, commercial ranching operations. Commercial farming, timbering, and mining also flourished (Harper et al. 1943:48).

The livestock industry expanded tremendously in the 1870s and 1880s, not only in numbers but also in geographic extent. Though overcrowding of the range and drought in the 1890s caused reductions in stock numbers, there were still three and one-half million sheep (Carlson 1969:37-39) and one million head of cattle at the turn of the century (Elson 1992). Sheep numbers had peaked at five and one-half million in 1884 (Carlson 1969:37). Over-expansion of the livestock industry led to overgrazing with subsequent vegetation loss and soil erosion in this arid environment, as did large-scale timber harvesting. Both of these negatively impacted water quality of both tributary streams and the Rio Grande itself (Eastman et al. 1971:6).

In order to deal with problems of land degradation and overexploitation of resources throughout the west, the thrust of federal legislation changed from promotion of intensive resource use to promotion of resource conservation. As a part of this effort, Forest Reserves were established in the early 1900s. In the northern and central portion of the state, these reserves later became the Carson, Santa Fe, and Cibola National Forests. These forests encompass all or portions of various former land grants that were lost to the original grantees. Twenty-two percent of the Santa Fe and Carson Forests comes from lands that had been used by Hispano villages, primarily as community grant lands (Eastman et al. 1971:6-7; de Buys 1985:235-277). Somewhat more than 25% of the land area of northern New Mexico, and over 40% of Taos County, lie within the National Forest system (Hassell 1968:2; de Buys 1985:255).

Many of these lands came into federal control in seriously degraded condition. Rehabilitation work is ongoing today. Much of this work focuses on restoring degraded range land by means of reduction in stock numbers, development of rotational grazing systems, and movement of animals out of severely impacted areas. Federal land managers also often insist on improvements such as fencing and the development of waters, which ranchers who graze their animals on federal lands (permittees) are supposed to help construct and maintain. They may then graze their animals on forest land, in the cases under discussion, for fees that are considerably less than would be charged on private lands. However, since many of the permittees are the descendents of former grantees, they often deeply resent government restrictions and payment to use land they consider to be rightfully theirs.

IMPORTANCE OF DOMESTICATED ANIMALS IN THE RURAL VILLAGES

Anglo-American influence has increased considerably in the region since the depression. In the ensuing years, the history of the small Hispano communities located near the National Forests has been one of continued land loss, economic decline, and poverty. Economic need has forced people from the land and out of the villages into migrant labor and removal to the cities (Rodriguez 1987:381). Those who stay often commute to wage work in a nearby city. For those who remain in the small communities, their domesticated animals have an importance that is out of proportion to their numbers.

Most of the small-scale livestock operators do not depend on their animals for their full support; they generally have outside jobs of some sort. They see their animals first and foremost as a means of savings, as banks-on-the-hoof, which can be used in hard times. Animals serve as a back-up resource for emergencies, for periods of unemployment, or for special needs like college tuition for the children. They also add to subsistence security by providing meat and milk for the family no matter what the supermarket price is or the condition of family finances. In some years, a small profit may be made if some animals are sold. Even small gains can be very important to families operating at or below the poverty level (Eastman and Gray 1987:39-50; Raish 1992; William de Buys, personal communication, 1995).

In addition to the economic considerations, small-scale livestock producers stress the importance of the quality of life that ranching provides them and their families. They speak in terms of preserving a working relationship with the land that can be passed on with pride to their children and of the importance of self-sufficiency and frugality that the rural life teaches. Owning animals is very important to them as a way of reaf-

firming ties to their ancestral lands and heritage. Cooperative work arrangements and participation in livestock related community events such as branding and butchering also help to keep alive social cohesion in the community. In many cases, the extra buffer that the animals provide allows the family to stay in the ancestral, rural community and continue at least a portion of the traditional lifestyle (Eastman and Gray 1987:39-50; William de Buys, personal communication, 1995). The more rural and remote the community, the more important the ranching option becomes.

LAND GRANT LOSS AND HISPANIC GRAZING PROTEST

Considering the importance of domesticated stock to the rural villagers, it is no surprise that federal agency attempts at range restoration, conservation, and grazing regulation have been met with considerable opposition in some areas. Community grant losses limit the grazing areas open to many villagers. For example, the small community of Cañones, located near the northern portion of the Santa Fe Forest, lost community grant lands to speculators who ultimately sold the land to the federal government in 1937. As a result, 89% of the Cañones valley is owned by the Forest Service, and the village is surrounded on three sides by National Forest (Van Ness 1987:201).

Patterns of overstocking, attempts at range improvements, and negative reactions to improvement programs are clearly seen on the Carson and Santa Fe Forests. In a Forest Service report of 1938, it was estimated that demand for grazing on portions of the Carson and Santa Fe exceeded potential by 111% (Hassell 1968:12). In the late 1960s, estimates showed grazing obligations on the two forests to be for 21,637 cattle and 32,203 sheep, compared to an estimated capacity of 14,370 cattle and 25,237 sheep.

Dating especially from the 1920s and accelerating in the period from the 1940s through the 1960s, livestock ranching on the two forests underwent tremendous changes as the economy changed and as the Forest Service implemented range improvement programs (de Buys 1985:247-249). There was a steady decline in both the number of permits and the number of animals permitted, from 2200 permits in 1940 to fewer than 1000 in 1970. Stock numbers were also reduced with some areas undergoing substantial cutbacks in the attempt to bring animal numbers in line with range capacity. The people of Cundiyo, who grazed their animals on the east side of the Pecos Wilderness, had herd reductions of 60%, while the permittees of Canjilon lost permits for 1000 cattle over a period of a few years (de Buys 1985:247-259). Free-use permits, issued for animals used in household operation such as milk cows and draft horses, were completely phased out by 1980. Also during this period, there was a major change in the kinds of animals being grazed, with massive declines in the numbers of sheep and goats under permit. By 1980, there were no goats on either forest and no sheep on the Santa Fe (de Buys 1985:247-248; Van Ness 1987:202). These significant changes came about both as a result of Forest Service direction and as a result of changes conditioned by the switch from a subsistence-based to a cash-based economy. Land losses and cutbacks in herd size undoubtedly pushed many people into the cash-based economy of wage work.

Throughout this period (1940s-1960s), considerable animosity developed between the Forest Service and the villagers. In 1967, protest coalesced in the form of the now-famous Tierra Amarilla Courthouse raid led by Reis Lopez Tijerina, founder of the Alianza Federal de Los Pueblos Libres, known as the Alianza. Two of the main goals of the protest were to bring the problem of massive land grant loss to world attention and to address a series of grievances concerning management of grazing on the National Forests.

FOREST SERVICE RESPONSE TO HISPANIC PROTEST

In the wake of the protest, there was considerable reexamination of Forest Service policies in northern New Mexico. The Forest Service produced the Hassell Report, titled The People of Northern New Mexico and the National Forests (Hassell 1968). The report recommended 99 measures, 26 of which related to grazing, to improve the situation of the Hispanic villagers. Many of these were implemented, more money was brought into the region, and progress was made.

In addition, the Forest Service developed a special policy for managing the forests of northern New Mexico.

What came to be known as the Southwestern Policy on Managing National Forest Lands in the Northern Part of New Mexico, or the North New Mexico Policy, had a philosophical base that stressed the importance of valuing and preserving the Hispanic and Indian cultures of the Southwest (Hurst 1972). Implementation was based on the recommendations of the Hassell Report (1968). Over the years, several progress reviews were conducted on implementation of the recommendations. After the final review in 1981, the Forest Service decided that a separate policy statement for the area was no longer needed and that further implementation would be through Regional and Forest mission statements and plans (Hassell 1981).

A review of several of the issues surfaced by Hispano groups in the late 1960s and addressed in Hassell's recommendations gives valuable information on the present-day status of these concerns on the two northern forests, with the majority of information drawn from the Santa Fe. These issues highlight both ongoing problems and areas of cooperation between the villagers and the Forest Service. Primary issues of concern, of course, have been stock reductions, reductions in numbers of permittees, consolidation of small permits, and elimination of free-use permits. Recommended changes in traditional livestock and range management procedures have also been topics of debate.

To deal with the problem of stock reductions and declining numbers of permits, various measures were suggested. These included continuing a high level of funding for range improvement programs, but discouraging crash programs designed solely to create forage and greatly increase grazing capacity. The report also recommended developing education programs showing the limitations of the range resource, so that false hopes would not be raised (Hassell 1968:14). As of 1995, both stock reductions and reductions in numbers of permittees had slowed very considerably. The big reductions had already occured prior to and into the 1970s.

There were some extensive forage creation programs on the two forests, however. These were undertaken primarily in the late 1960s and early 1970s as a result of expanded range funding. On Rowe Mesa south of Pecos, for example, ca. 13,000 acres were stripped of vegetation and converted to grassland. Cattle that had formerly grazed in the Pecos Wilderness were relocated to a portion of these lands (de Buys 1985:268). Unfortunately, many of these forage development projects had only limited success and were quite costly. Some were not well thought out, promising more than they could deliver and not considering other resources. In addition, much of the removed vegetation was pinyon-juniper, which created a fuelwood shortage in some areas (Dave Stewart, personal communication, 1995). As predicted in the initial recommendations, more lasting improvements have been achieved with more moderate range improvement and education programs (Hassell 1968:14). Expanded funding for range development is no longer being received by the Santa Fe (Jerry Elson, personal communication, 1995). The two northern forests are currently funded in the same way as the other forests of the region.

In addition to stock reductions and reductions in numbers of permittees, other areas of strong local concern focused on measures that eliminated special free-use permits for stock used in household operations and facilitated the reduction of small permits. Free-use permits were decidedly on the wane by the late 1960s and were never reinstated. Hassell (1968:15-16) recommended that they be completely eliminated owing to the environmental damage caused in areas close to the communities where the animals were constantly grazed, similar to the damage caused by close-in grazing during the Spanish Colonial period.

Small permits were also declining during the late 1960s at the time of the protests. A special grazing permit transfer policy on the Carson and Santa Fe prohibited transfer of a permit for less than 25 head to someone who did not already hold a permit. The objectives of the policy were to encourage consolidation of small permits into larger ones and also to retain permits with existing, local ranchers (Hassell 1968:19-21). Retention of permits within the local area was indeed beneficial for the small, rural communities, but forced consolidation was not. The majority of stock operations on the northern forests were small and were consistent with the village lifestyle, which held the stock as a partial subsistence and back-up resource, not as a commerical venture. Hassell's

report came out in favor of maintaining the small permits and actually creating more opportunities for small operations, if feasible (Hassell 1968:19-21).

Maintenance of small permits is certainly the case today on the Santa Fe (John Phillips, personal communication, 1995), though there are differences between the northern and southern portions of the forest. Large herds are not required and some permits have as few as four head. Areas in the southern part of the forest, within commuting range of the large urban centers, tend to have less emphasis on ranching with fewer permittees. Ranching emphasis is also a function of the nature of the land, of course. The Jemez District, for example, currently has 12 active grazing allotments, most of which are community allotments. Community allotments have more than one permitted individual using the allotted grazing land, so that the Jemez allotments have approximately 30 permittees. Herd size ranges from 150 to over 200 head for the four or five people who are full-time ranchers, down to six head. Most of the permittees are week-enders who commute to full-time jobs elsewhere.

The northern part of the Santa Fe is more remote, with fewer opportunities for outside employement and a stronger ranching traditiion. On the whole, there are more permittees and community allotments in this area, but there are fewer head per owner. Many have herd sizes of 10 or 12, but those 10 or 12 head are very important to the economics of the families who own them. These families are also more dependent on forest products for their livelihood than are forest users in other areas. They more closely approximate the rural villagers for whom the North New Mexico Policy was developed.

Finally, ongoing problems with implementation of range improvement programs that require departures from traditional livestock and range management practices were examined. These provide good information on land use practices that still cause environmental problems which must be solved, if sound ecosystem management strategies are to be implemented. Hassell acknowledged the difficulty of persuading ranchers to depart from traditional ways and the additional difficulty of dealing with large numbers of permittees involved on each allotment. He recommended agency assistance and education, especially during initial implementation of new rest-rotation programs, for example (Hassell 1968:18-19). Discussions with the professional range staff on the Santa Fe indicated that the large number of permittees and small herd sizes throughout the forest do indeed make the work more difficult and slow progress (Jerry Elson and John Phillips, personal communications, 1995). On the other hand, there is a strong awareness of the importance of the animals to the families who own them and a strong commitment to continue working with them to improve the condition of the range.

Many good projects and programs have been implemented in all areas of the forest in recent years, and there is increasing cooperation between the forest and the permittees in many areas. The Jemez District has recently completed a project on a portion of the East Fork of the Jemez River that has heavy recreation use, with environmental problems caused by overuse from both people and livestock. Livestock problems have been solved by adding range improvements in the form of fencing to keep the cattle in newly designated pastures that are not adjacent to the river (John Phillips, personal communication, 1995). As another example, the Coyote District recently won a Stewardship Award from the Environmental Protection Agency for watershed improvement work on the French Mesa Allotment.

Nonetheless, problems still remain over issues of range use, economics, and environment. In general, these problems are more entrenched and deeply rooted in the northern portions of the forest than in the southern areas. The more remote, northern communities located adjacent to the forest have considerably less economic opportunity than those communities nearer urban areas. The residents are more dependent on the forest lands for pasture, fuelwood, and other resources. Resentment of land loss to the federal government is still strong, as is resistance to altering traditional ways of doing things and accepting counsel from outsiders. Many of the problems discussed in the Hassel Report (1968) almost 30 years ago with respect to quality of life and quality of the land still remain. If sound environmental practices and ecosystem management are to be implemented in these areas, future research must focus on developing means of balancing resource conflicts between meeting human needs and preserving the quality

of the environment. The lessons of the past must be used to help design management practices for the present that protect the natural resource but do not ignore the human resource. Though special cultural conditions and traditional lifeways cannot be used as an excuse to ignore environmental degradation, neither should one-size-fits-all management practices be applied.

CONCLUSION

In order to understand the present-day configuration of the cultures that co-exist in northern New Mexico, it is necessary to understand the historic background of these groups and their subsistence practices. The village farming lifeway of the rural Hispanos has existed in the area for over 350 years, antedating Anglo-American control by 250 years. This lifestyle incorporates stock raising and forest use as vital parts of an economy that is distinct from large-scale Anglo-American commercial ranching and farming in other parts of the state. Though many economic changes have occurred in the small villages in the twentieth century, preservation of ties to the land is vital to preservation of the cultural traditions of the area.

ACKNOWLEDGMENTS

I would like to thank Dave Stewart, Range Administration Southwestern Region, USDA Forest Service; Jerry Elson, Range and Wildlife Staff, Santa Fe National Forest; and John Phillips, Range/Watershed Specialist, Jemez Ranger District, Santa Fe National Forest; for their help in the preparation of this paper.

REFERENCES

Baxter, John O. 1987. Las carneradas: sheep trade in New Mexico, 1700-1860. Albuquerque, NM: University of New Mexico Press.

Carlson, Alvar Ward. 1969. New Mexico sheep industry, 1850-1900: its role in the history of the territory. New Mexico Historical Review. 44(1): 25-49.

Crosby, Alfred. 1972. The Columbian exchange: biological and cultural consequences of 1492. Westport, CN: Connecticut.

de Buys, William. 1985. Enchantment and exploitation: the life and hard times of a New Mexico mountain range. Albuquerque, NM: University of New Mexico Press.

Earls, Amy Clair. 1985. The organization of Piro Pueblo subsistence: A.D. 1300 to 1680. Albuquerque, NM: University of New Mexico. Ph.D. dissertation.

Eastman, Clyde; Carruthers, Garrey; Liefer, James A. 1971. Evaluation of attitudes toward land in north-central New Mexico. Las Cruces, NM: New Mexico State University. Agricultural Experiment Station Bulletin 577.

Eastman, Clyde; Gray, James R. I987. Community grazing: practice and potential in New Mexico. Albuquerque, NM: University of New Mexico Press.

Elson, Jerry W. 1992. Tri cultures of New Mexico. Rangelands. 14(5): 261-264.

Hammond,George P.; Rey, Agapito. 1953. Don Juan de Onate, colonizer of New Mexico, 1595-1628 (1). Albuquerque, NM: University of New Mexico Press.

Harper, Allan G.; Cordova, Andrew R.; Oberg, Kalervo. 1943. Man and resources in the middle Rio Grande valley. Albuquerque, NM: University of New Mexico Press.

Hassell, M. J. 1968. The people of northern New Mexico and the national forests. Albuquerque, NM: USDA Forest Service. Southwestern Region. Manuscript on file.

Hassell, M. J. 1981. Northern New Mexico policy review and action plan. Albuquerque, NM: USDA Forest Service. Southwestern Region. Memo on file.

Hurst, William D. 1972. Region 3 policy on managing national forest land in northern New Mexico. Albuquerque, NM: USDA Forest Service. Southwestern Region. Memo on file.

Melville, Elinor G. K. 1994. A plague of sheep: environmental consequences of the conquest of Mexico. Cambridge: Cambridge University Press.

Raish, Carol. 1992. Domestic animals and stability in pre-state farming societies. Oxford, England: Tempus Reparatum. BAR International Series 579.

Rodriguez, Sylvia. 1987. Land, water, and ethnic identity in Taos. In: Briggs, Charles L.; Van Ness, John R., eds. Land, water, and culture: new perspectives on Hispanic land grants. Albuquerque, NM: University of New Mexico Press.

Rothman, Hal. 1989. Cultural and environmental change on the Pajarito Plateau. New Mexico Historical Review. 64(2): 185-211.

Scurlock, Dan. 1995a. Environmental history. In: Finch, Deborah M.; Tainter, Joseph A., eds. Ecology, diversity, and sustainability of the middle Rio Grande basin. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, General Techhnical Report RM-268: 12-28.

Scurlock, Dan. 1995b. Middle Rio Grande basin environmental history: an overview of resource management and conservation, 1846-1980. Albuquerque, NM: USDA Forest Service. Rocky Mountain Forest and Range Experiment Station, Albuquerque Lab. Manuscript on file.

Simmons, Marc. 1979. History of Pueblo-Spanish relations to 1821. In: Ortiz, Alfonso, ed. Handbook of North American Indians: Southwest (9). Washington, DC: Smithsonian Institution: 178-193.

Van Ness, John R. 1987. Hispanic land grants: ecology and subsistence in the uplands of northern New Mexico and southern Colorado. In: Briggs, Charles L.; Van Ness, John R., eds. Land, water, and culture: new perspectives on Hispanic land grants. Albuquerque, NM: University of New Mexico Press: 141-214.

Wozniak, Frank E. 1995. Human ecology and ethnology, In: Finch, Deborah M.; Tainter, Joseph A., eds. Ecology, diversity, and sustainability of the middle Rio Grande basin. Fort Collins, CO: USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report RM-268: 29-51.

Tribal experiences and lessons learned in riparian ecosystem restoration

Ronald K. Miller[1], James E. Enote[2], and Cameron L. Martinez[3]

Abstract.—Riparian ecosystems have been part of the culture of land use of native peoples in the Southwest United States for thousands of years. The experiences of tribal riparian initiatives to incorporate modern elements of environment and development with cultural needs are relatively few. This paper describes tribal case examples and approaches in riparian management which may advance discussions of cultural values in resource management for rural and developing communities such as those on tribal lands in the United States.

INTRODUCTION

"Mastamho drove a willow stick into the ground and drew out the water that became the Colorado River and with it came the fish and ducks. He gave the people the river and everything along the river. Whatever grew there was theirs, as he said, and they were the Aha Macave, the Mojave, the people who live along the river."

So states the Mojave's creation story. The story provides background and valuable insight into the significance of a particular river to tribal custom and culture. This relationship between the Mojave people and the Colorado River is further explained on a brass plaque on the Fort Mojave Reservation where the present day states of Nevada, Arizona, and California meet:

"For the Aha Macave the river was the center of existence. They practiced a dry farming method, relying on the regular overflow of the Colorado River to irrigate crops planted along the banks. They supplemented this with wild seeds and roots, especially mesquite beans, and game and fish taken from the river with traps and nets."

For many tribes in the arid Southwest, rivers, streams, and springs were, and continue to be, the "center of existence." Neither the people, nor the unique cultures that developed, could survive without the "lifeblood of the desert": The Southwest's rivers and streams.

CENTERS OF EXISTENCE

Most Southwest tribes still live along the river courses and depend on them for a wide variety of uses. Sharing the Colorado River with the Mojaves are almost a dozen other tribes. Upstream are the Navajo, the Havasupai, and the Hualapai. Downstream are the Chemehuevi, the Colorado River Indian Tribes (consisting of four tribal groups), the Quechan at Fort Yuma, and the Cocopah.

Major tributaries of the Colorado River also play host to many tribes in Arizona. The White Mountain and San Carlos Apache reservations are separated by the Black River, which as it flows westward becomes the Salt River. As this river continues downstream, it gives its name to a reservation whose southern boundary it forms: the Salt River Reservation, home to Pima and Maricopa people. Their reservation also plays host to the Verde River, a beautiful river that first serves as a centerpiece to the Fort McDowell

[1] *Woodlands Forester, USDI Bureau of Indian Affairs, Phoenix Area Office, Phoenix, AZ.*

[2] *Project Leader, Zuni Conservation Project and Department Head for Natural Resources, Pueblo of Zuni, Zuni, NM.*

[3] *Forest Manager, USDI Bureau of Indian Affairs, Northern Pueblos Agency, San Juan, NM.*

Indian Reservation. The Verde and the Salt become one on the Salt River Reservation and continues to flow westward to form the northern border of the Gila River Reservation. This reservation, as its name implies, is bisected by the flowing waters of the Gila. As the Gila flows out of the reservation and joins the Salt, it takes its name with it causing the Salt River to once again change its name. This western stretch of the river with its increased flow, in turn, travels through yet another reservation and once again gives the reservation its geographic namesake. The Gila Bend Reservation, a district actually of the Tohono O'odham Nation, is the last reservation the river passes through before continuing west to join the Colorado River's southern migration.

Even for Arizona tribes whose present location may not make the riparian connection obvious, there is almost always a cultural link. The Ak Chin reservation, south of Phoenix, currently lacks any flowing streams, in part because heavy ground water pumping has depleted much of the available water in the area. Historically, however, the Ak Chin were nomadic farmers who followed the water that made their land arable. Their tribal name, in fact, means "Mouth of the wash".

In New Mexico, a majority of the tribes center along the Rio Grande. The Tewa, Tiwa, Towa, and Keresan settled along the Rio Grande living in close knit communities that the Spanish later named the pueblos of Taos, San Juan, Santa Clara, San Ildefonso, Tesuque, Cochiti, Santo Domingo, San Felipe, Santa Ana, Sandia, and Isleta. Other Pueblos not directly on the Rio Grande, line tributaries of the Rio Grande such as the Jemez river which the Jemez, Zia, and Santa Ana reservations all share. Their Zuni cousins settled along the Zuni River in western New Mexico.

When tribal peoples of the Southwest discuss what scientists and land managers call riparian areas there is a definite duality in how these areas are defined. For tribes of the Southwest, the heritage of land use includes riparian areas and is an inherent component in many of these cultures. In deeper religious terms, riparian areas are extremely important icons of survival, continuance, and reverence for societies and people long passed away. But the esoteric religious knowledge and importance of riparian areas is also secret and private in its meaning and use. In these expressions, riparian areas have values which are nonquantifiable.

In academic and economic standards, efficient productivity is a desirable goal and riparian areas are resources with quantifiable values to be preserved or perhaps shared for multiple uses. These values and how they are taken into consideration are at the center of planning riparian area management on Indian lands in the Southwest.

As tribes prepare for the twenty-first century, a reshaping of tribal capability has begun and new perspectives are coming to light on how riparian areas will contribute to the needs of tribal peoples and the dependent life forms on tribal and adjacent lands. There are needs which must be addressed before plans of action can be drawn, and there are issues which must be discussed and dealt with before planning can begin.

SEEKING A BALANCE

A visitor to Indian country will almost certainly be amazed at the ability of tribes to get things done with their complicated theocratic and democratic governing systems. But things do get done, albeit in a different sort of way. Tribes may have different languages, customs, and indigenous religions, but each shares a common thread of belief which assures continuance and sustainability of the people. It is within this weave of beliefs that a fabric evolved which allowed these tribes to live in the same areas for centuries before this great republic was created. As tribes seek a balance between maintaining cultural identity and accepting aspects of modern land management, there are strategies emerging which are uniquely their own design and strategies which are nearly complete templates of national standards. In some cases there are hybrids of both systems.

It is important for non-Indians to understand that each tribe has a certain way of doing things, much relating to the history and culture of the respective tribe. In the case of riparian lands, there is a whole spectrum of possibilities for protection or development, and far more choices than are available on state or federal lands. Case examples of different tribal approaches to riparian ecosystem restoration are described below.

FORT MOJAVE AND COLORADO RIVER INDIAN TRIBES

Tribal members on the Fort Mojave and Colorado River Indian Reservations still extensively use the Colorado River. It provides an ever present source of irrigation water for their extensive agricultural fields, a home for the many species of wildlife that utilize the river corridor, and a tourist magnet for water-based recreational activities.

The river also provides favorable mesic habitat for plant species having important significance both ecologically and culturally. Mesquite is especially valued as it supplies wood for cradleboards, beans for food, and is used in combination with arrowweed in funeral pyres for traditional Mojave cremations. Willows provide material for basket making. Historical documentation, oral tradition, and legends all point to the many cultural connections the tribe has with the river and those plant and animal species tied to the riparian ecosystem.

Two recent fires (Spring, 1995) which burned an estimated 90% of Fort Mojave's mesquite were devastating to the tribe. A fire rehabilitation team was mobilized to immediately prepare a plan to reestablish mesquite on the most suitable sites. The rehabilitation team's concerns covered the entire gamut of possible natural resource degradation resulting from the fire but, at least on tribal land, the overriding concern was the loss of mesquite because of its cultural importance. Restoration efforts will focus on reestablishing this important tree on tribal land.

In the meantime, on the Colorado River Indian Reservation, a comprehensive plan has just been completed to establish a 1,042 acre riparian wilderness preserve and recreation area. Plans for the area include widespread revegetation with native riparian plant species, control of exotics such as saltcedar, and maintenance and improvement of a backwater area for fish and wildlife habitat. Hiking trails, also planned for the area, include a nature trail to educate visitors about riparian ecosystems, and a cultural trail focusing on Mojave history and way of life. A cultural center and an elder's village are also planned.

ZUNI INDIAN RESERVATION

In the remote plateau and canyon country of west central New Mexico, the Zuni Tribe has created a unique program of watershed restoration and riparian conservation based on Zuni cultural values and assessments of geomorphic processes. The work began as a result of a law suit brought against the United States for improprieties related to trust responsibilities.

The case was eventually settled out of court in 1990 and a substantial trust fund was established from which interest would fund watershed restoration and sustainable development of Zuni resources in perpetuity.

In late 1991, the Zuni Tribe established the Zuni Conservation Project to lead a program of watershed restoration and resource development which includes riparian restoration. Based on interviews with religious leaders, farmers, livestock growers, and other land users, attention to the culture of Zuni land use became the scope and mission of Zuni's efforts in environmental restoration and land use planning.

By 1993, the Tribe had completed a plan of action for sustainable resource development in the format of the United Nations Agenda 21 document. The U.N. Agenda 21 serves a blueprint for sustainable resource development and was as negotiated for several years among over 140 nations. Zuni's version of Agenda 21 was created using a participatory approach among Zuni land users. In the course of the law suit against the United States, Zuni elders and religious leaders gave depositions and interviews on behalf of the Tribe detailing an image of Zuni lands hundreds and even thousands of years ago. Zuni riparian areas were described as being more extensive, abundant with species diversity. Consequently, enthusiasm to restore Zuni riparian areas grew. The challenge for the Conservation Project has thus become two fold. As a culturally based project, riparian areas and species diversity are foremost concerns for Zuni religion and consultations and planning with religious leaders directly reflect this. As a restoration project, creating a program to achieve riparian area diversity required planning on a watershed scale.

The Zuni Conservation Project enlisted the knowledge of elders and use of traditional water

control features, as well as a sophisticated array of geomorphic study stations and geographic information systems. Before implementing a broad reservation-wide program, a pilot area was chosen where relationships among disciplines involved in the project could be evaluated and relationships with land users examined. As the project progressed, low impact techniques using hand labor and natural materials have become standard for watershed and riparian work. In a few cases, beavers have been transplanted to sites with diminished water levels where they have constructed dams, raising water levels considerably.

Establishing riparian vegetation has been successful as well, and efforts are underway to create a local plant materials center to propagate plants for transplanting into riparian areas and damaged watersheds.

The work to conserve riparian areas naturally requires participation from the land users and compromises have had to be developed to provide alternative watering sources for livestock and in some cases wildlife. In this respect, riparian projects in Zuni are not discrete projects, but rather involve broad participation of land users and managers. The Zuni example is a fortunate one in that cultural values contribute to the preservation and conservation of riparian areas as inherent necessities for Zuni continuance and spiritual well being. Several keys to developing riparian projects have been learned at Zuni through experience and observations of other projects with similar cultural based agendas. Principally, there are seven key areas:

- Legislation to support efforts
- Human resource development and capacity building
- Appropriate technologies
- Communications in local languages
- Financing for sustained project life
- Legal instruments to support the work (codes and regulatory laws)
- Cultural significance

The process of participatory development for riparian lands in Zuni is always evolving. In the first year of the project the issues and needs were broadly defined. By the second and third years, plans of action were implemented, monitoring parameters defined, and financing for long term continuance of the project set in place.

RIO GRANDE PUEBLOS

To understand the current Rio Grande ecosystem, it is important to understand some of its history. The pueblos along the Rio Grande were already several hundreds of years old when the Spanish conquistadors arrived in 1540. As in the Southwest as a whole, the native people depended on the river and its tributaries for all aspects of life. With this dependence and use came changes. Trees were cut to provide house timbers and fuel. This continuous removal of wood often left areas completely devoid of fuelwood and building materials for many miles around a pueblo, and may explain why some pueblo settlements were deserted after fifty to one hundred years of habitation. The destructive effect was lessened because populations were relatively low, and in pre-Spanish times, carriage of logs had to be on human shoulders. There was, however, considerable erosion in the uplands, and the removal of small stands of timber in the cottonwood bosques often led to local flooding.

The Spaniards too, were heavy users of wood, and they introduced large herds of domestic sheep. These animals, by their close cropping of vegetation in the semiarid Southwest, contributed to rapid runoff and soil erosion, especially along some tributary streams.

By the twentieth century, major water control systems were in place, a huge increase in human and stock-animal populations evolved, and an insatiable urban demand for water began to fundamentally modify the Rio Grande region.

Currently, the Rio Grande pueblos are taking measures to restore their riparian areas and to improve the quality of water. These changes have come about with help from some farsighted individuals at the pueblos of Tesuque, Nambe, Santa Clara, San Ildefonso, San Juan, Picuris, and Taos. Examples of riparian restoration taking place in three of these pueblos is briefly discussed below.

Pueblo of Tesuque

The Pueblo of Tesuque is monitoring their cottonwood-willow bosques along the Rio Tesuque and associated perennial streams to

determine the effects of disturbance on this biological system from changes in species diversity, ecosystem stability, and biomass. Habitat management decisions for wildlife are frequently made by considering a limited set of species, e.g., common game species or endangered species. Some groups, such as bird species, respond quickly to changes in habitat structure because of their mobility. Tesuque's study has already collected data on these aspects and may confirm bird responses to the overall value of mitigating riparian losses solely by changes in vegetative cover. It may indicate that restoration of disturbed riparian faunas might require reintroduction of bird species, in addition to changes in vegetative complexity and to replicate full community structure and richness. It will also aid the tribe in making habitat decisions and monitoring environmental effects from off-reservation actions which affect avian populations necessary in cultural activities of the tribe.

Pueblo of Nambe

The Pueblo of Nambe derives income from the recreation area it has developed over the years along the Rio Nambe and Pojoaque Creek. This important resource, known as the Nambe Falls and Recreation Area, serves the Santa Fe and Espanola communities year round. Increasingly, the tribe is striving to manage the recreation area for multiple types of recreation and other resources. Multiple resource concerns center around fish and wildlife habitat, water quality, water conservation, aesthetics, cultural aspects, erosion control, and water conveyance. To help meet this broader focus, the tribe, assisted by the Bureau of Indian Affairs and the U.S. Forest Service, conducted a riparian evaluation based on the recreation area's goals and objectives. Following the evaluation's recommendations, approximately twenty acres along the Rio Nambe have been interplanted with native plant species such as mountain mahogany, Gamble oak, sumac, chokecherry, and willow. Narrowleaf cottonwoods were also planted along the shores of Nambe Lake at twenty picnic table sites. Many other revegetation projects are planned for the future. The overall survival rate for these projects has been about 85% for all species planted due in part to a watering program implemented by the recreation area staff.

Pueblo of San Juan

The Pueblo of San Juan is one of a few tribes in New Mexico to have a Forest Stewardship Plan. This program is a combined federal and state program which provides cost-share funds to implement forest conservation practices. As program cooperators, the Pueblo is managing its landbase to maintain cultural ties for the benefit of current and future generations. Channelization of the Rio Grande was and still is threatening the riparian vegetation. The tribe wished to restore these areas without destroying existing residential areas or farmlands. The riparian areas are to be developed to provide for recreation and wildlife habitat, as well as to provide wood for future economic development and maintenance of the culture.

Approximately 200 acres on the reservation were identified as riparian. Goals for these areas include elimination of exotic vegetation such as Russian olive and saltcedar, planting of native peach leaf, coyote, and Gooding willows and Rio Grande cottonwood, interplanting of grain crops with willow and cottonwoods strips to enhance wildlife food and cover, and establishment of water table monitoring devices. The willows are important to reestablish the riparian ecosystem and to provide material for culturally important activities. "Shinny sticks" for a tribal stick game similar to golf, willow furniture, and baskets are all made from willows. Thus far, in its first year, the tribe has implemented the planting of Rio Grande cottonwoods on ten acres.

FERTILE OPPORTUNITIES

Tribal experiences and lessons learned in riparian ecosystem restoration offer resource managers a broad array of information. This discussion described how some tribes employ old, time-proven traditional technologies, modern high technologies, or both. There are many different objectives as well. No matter what the differences may be, innovation and adaptability are common and planning has been shaped around widely-discussed and accepted goals of tribal communities. Though some efforts may be embryonic, and mistakes have been made, many tribes have become a regional influence and leaders in combining the "cultures of land use" with progressive management strategies.

Rio Grande Basin Consortium: Mission, goals, and activities

Deborah A. Potter[1] and Deborah M. Finch[2]

Abstract.—The Rio Grande Basin Consortium (RGBC) serves as a networking group and clearinghouse for scientific information pertaining to the Rio Grande Basin. Its membership consists of natural and social scientists from New Mexico's three research universities, administrators, and resource managers from federal, state, and local governmental agencies, members of community and advocacy groups, and private citizens. Members share an interest in better understanding the physical, ecological, economic, social, and cultural dynamics of this drainage area. In this report, we briefly describe the history, mission, goals and objectives, past and current projects and partnerships, and funding of the Consortium.

INTRODUCTION

The Rio Grande Basin Consortium (RGBC) emerged from University of New Mexico's (UNM) Faculty Scholars' Program of 1989. It formed under the leadership of Dr. Jim Gosz and Dr. Eleonora Trotter (UNM Biology Department) primarily to serve as a networking group and clearing house for scientific information. Deborah M. Finch, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Albuquerque, NM serves as current Consortium Chair and Dennis Engi, Sandia Laboratories, serves as Executive Director. The Consortium's most recent past Chair and Executive Director were Sarah Kotchian, City of Albuquerque, and Deborah Potter, USDA Forest Service, Southwestern Region, respectively. Many individuals have served on steering committees, especially participants from the UNM Natural Resources Center: Chris Nunn, Lee Brown, and Michele Minnis. The first major activity hosted by the Consortium was a conference entitled *The Rio Grande Basin Global Climate Change Scenarios* held on June 1-2, 1990. The published proceedings (Stone et al. 1991) contained the Consortium's draft mission and goals which are still in place, with minor modification, today. The Consortium has continued to expand its interdisciplinary partnerships while maintaining established communication and information networks.

The mission of the Rio Grande Basin Consortium, revised at a business planning meeting held August 8, 1995, is "to provide a forum for diverse constituencies to address the current and future status of the Rio Grande Basin. We do this by improving understanding of the Basin, sharing that knowledge broadly and effectively to support informed decision-making, and fostering interdisciplinary cooperation."

The goals of the Consortium are to:

1. Increase awareness of the Rio Grande Basin as a fragile invaluable ecosystem with a unique cultural heritage, and increase commitment to the actions necessary to preserve the Basin;
2. Develop understanding of the interactions of economic, environmental, and cultural process within the Basin through the integration

[1] *Past RGBC Executive Director and General Physical Scientist, USDA Forest Service, 517 Gold Avenue SW, Albuquerque, NM 87102.*

[2] *RGBC Chair and Project Leader, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, 2205 Columbia SE, Albuquerque, NM 87106.*

of new information, scientific data, and indigenous knowledge and values;

3. Involve local communities in decision-making processes that result in more relevant and effective policies affecting the sustainability of the Basin;
4. Promote interdisciplinary, interagency, and international cooperation.

Consortium objectives are to:

1. Facilitate a process through which sustainability of the Basin will be enhanced by dialogue between diverse groups on values and issues in the Basin, leading to the establishment of common goals and joint actions for the future.
2. Enhance the exchange of information and multi-disciplinary data on the Basin in order to better understand the interactions of systems and values within the Basin.
3. Improve scientific inquiry through incorporation of local knowledge, and transfer scientific knowledge for use in decision-making by communities.
4. Maintain an active network among Consortium members to link individuals, communities, and agencies, insure that policies and programs work towards sustainability, and increase funding for interdisciplinary, intercommunity, and interagency Basin projects.
5. Improve coordination and cooperation between communities and local, state, and federal agencies.
6. Be a model of interrelated research, education, and action for use by other regions in their efforts towards sustainability.

MEETINGS

In 1993, it was decided that the full Consortium would meet about four times per year, and it should continue to invite guest speakers. Meetings were held on October 15, 1993; January 21, 1994, on the topic of *Water Quality and Data Sharing*; and on March 25, 1994. Meeting notes are available.

Much effort was expended by Consortium members in planning and developing an all-Basin conference entitled *Uniting the Basin* which was implemented under the Rio Grande/Rio Bravo Sustainable Development Initiative (SDI). Preconference planning meetings were held in Taos on May 21, 1993 and in Socorro on June 25, 1993 and February 14-16, 1994. Conference objectives included communication among geographic areas, the creation of an ongoing structure to pursue the sustainability of the Rio Grande Basin, and integration of regional perspectives within Basin-wide planning.

NEW PROJECTS AND PARTNERSHIPS

1. Rio Grande/Rio Bravo Sustainable Development Initiative (SDI).

Representatives from the Consortium served as the upper Basin working group in the all-Basin conference on sustainability entitled *Uniting the Basin*, May 19-22, 1994, in El Paso/Ciudad Juarez, Chihuahua. Nine Consortium representatives for the Upper Basin were: Blane Sanchez, Isleta Pueblo; Herman Agoyo, San Juan Pueblo; Brian Shields, Amigos Bravos; Chris Nunn, UNM; Sarah Kotchian, City of Albuquerque; Eleonora Trotter, UNM; Deborah Potter, USDA Forest Service; Wilfred Rael; Martha Quintana, and Chris Canaly, Citizens for San Luis Valley Water. At-Large members from the Consortium were Robert Woodmansee of TERRA Laboratories, Dale Pontius of American Rivers and Eluid Martinez, State Engineer. Jim Gosz of UNM/National Science Foundation and Michele Minnis and Lee Brown of UNM also attended. Pat D'Andrea gave a slide presentation.

A $25,000 grant to assist the Consortium's participation in the SDI Conference and provide for a Basin-wide preconference planning meeting was obtained from the General Service Foundation. The planning session was held in Albuquerque on February 13-15, 1994.

During the May conference, four themes were discussed in bi-lingual subgroups: Basin-wide sustainable development; local sustainable development; institutions throughout the Basin; and institutions along the Texas-Mexico border. A conference summary statement was published by

the Houston Advanced Research Center (HARC 1994). Copies may be obtained by writing to Center for Global Studies, HARC, 4800 Research Forest Drive, The Woodlands, Texas 77381.

The SDI was primarily funded by a $200,000 Ford Foundation grant administered by the Houston Advanced Research Center. Additional funding of $100,000 was made available for follow-up activities. Issues of the SDI newsletter *La Corriente* were published throughout the year (since July 1993). National Science Foundation funding of $25,000 for a follow-up workshop was obtained by HARC.

2. Sustainable Biosphere Initiative (SBI).

This initiative was established by the Ecological Society of America in August 1988 to define ecological research priorities: that research agenda was published in a 1991 issue of *Ecology*. The Rio Grande Basin was named as a regional global change demonstration area through the Initiative. On August 10, 1993, representatives of the Consortium formally discussed its interest in the Rio Grande as a demonstration project with representatives of SBI: comments delivered by Sarah Kotchian on behalf of the Consortium are available. A proposal dated October 20, 1993, was prepared to define a process for the demonstration. [SBI is currently funded by the National Science Foundation.] As a follow-up to the SBI meeting on August 10, 1993, a proposal dated October 20, 1993, was prepared to define a process for the Rio Grande pilot site according to the SBI Regional Action Plans: A Systems Approach to Link Scientific Knowledge and Resource Management Needs. After a second meeting on November 3, 1993, it was decided in Washington that the BLM would lead the demonstration project, and the RGBC would lead the associated action plan. SBI funding was not appropriated for the pilot studies.

3. Survey of Northern and Southern New Mexico Communities.

To prepare for the SDI, Consortium member, Chris Nunn surveyed 447 water users, agency personnel, and citizens of the Northern Rio Grande about their attitudes toward water and sustainable development. The results of 15 questions included in the survey are summarized in the July 1993 issue of the newsletter *La Corriente*.

4. Partnership with Amigos Bravos.

Brian Shields of Amigos Bravos (Taos) presented his work on a NM Statewide Rivers Assessment to the Consortium for input. This assessment and data base is being prepared by Amigos Bravos and the New Mexico Natural Heritage Program to provide a basis for improved resource allocation and conservation decisions.

5. Partnership with TERRA Labs.

The Terrestrial Ecosystems Regional Research and Analysis (TERRA) Laboratory in Fort Collins selected the Rio Grande Basin as a testbed for regional scale analysis of ecosystem processes. Acting Director, Dr. Doug Fox has been discussing potential partnerships between the Consortium and TERRA for testing collaboration technologies and other aspects of their decision support system that links natural and social sciences. TERRA facilitated an electronic brainstorming session using IBM Team-Focus software on April 15, 1993, to discuss Consortium topics such as SDI.

6. Research by USDA Forest Service.

The Rocky Mountain Forest and Range Experiment Station in Albuquerque received $400,000 in 1994 and 1995 for a proposal entitled *Watershed processes, riparian zone responses, and biological diversity of the Rio Grande Basin*. Partnerships with the Consortium included hosting research programs at Consortium meetings; participation in *Dia del Rio*, a celebration of the Rio Grande on October 21, 1995 (and thereafter); financial assistance to Deborah Potter, Consortium member, for graduate training at UNM; and Consortium poster display at the Riparian Symposium, September 18-22, 1995. Deborah Finch, current Consortium Chair, is Team Leader for this Forest Service Research Program.

7. Bosque Management.

Representatives of the Consortium met with the U.S. Fish and Wildlife Service on March 10, 1994, April 4, 1994, and September 28, 1994 to discuss

the Consortium's role in implementation of the Bosque Biological Management Plan (Crawford et al. 1993). The Director requested that the Consortium submit a proposal to begin implementation of the Plan, including funding a position. Members of the steering committee also met informally on April 7, 1994 with Sue deen Kelley of the Bosque Management Task Force established by Senator Domenici's Rio Grande Bosque Conservation Committee. The Consortium's RGBC proposal subcommittee met on various occasions including July 8, 1994. A formal proposal for the arrangement was drafted in August 1994, and a pre-proposal was submitted on September 6, 1994. Due to changes in FWS personnel, the Consortium's proposal was dropped; however, the Consortium is currently developing new ideas for addressing the Bosque Biological Management Plan. For example, the Consortium's sponsorship of *Dia del Rio* is a community involvement project designed to promote greater appreciation, understanding, and resources for the Rio Grande. While *Dia del Rio* includes the entire Rio Grande/Rio Bravo Basin, the Consortium is focusing its efforts on the middle Rio Grande where the Bosque is mostly found.

8. Sevilleta Long-Term Ecological Research (LTER).

Representatives participated in a meeting sponsored by UNM and USDA Forest Service (Rocky Mountain Forest and Range Experiment Station) February 9-11, 1994 and on July 26, 1994, to discuss information exchange and research coordination among agencies and groups active within the Rio Grande Basin. The group supported a legislative proposal to establish the Rio Grande Institute for Environmental Studies at UNM. The Consortium agreed to work cooperatively with the Institute and LTER toward our shared research goals.

9. Riparian symposium.

The Consortium held a quarterly meeting on September 18, 1995, in association with the symposium on *Desired Future Conditions for Southwestern Riparian Ecosystems: Bringing Interests and Concerns Together*, September 18-22, 1995, Albuquerque, NM. Deborah Potter and Deborah Finch presented a poster display about the Rio Grande Basin Consortium at the symposium, and this paper is the written version of the symposium poster. Information about *Dia del Rio* was presented at the symposium, during the poster session and in session announcements.

10. Dia del Rio.

The Consortium hosted the middle Rio Grande portion of the Basin-wide celebration, *Dia del Rio*, October 21, 1995. *Dia del Rio* is a citizen-led event organized under the Rio Grande/Rio Bravo SDI. *Dia del Rio* is both a call to action and a celebration of the basin's rich diversity, drawing attention to the critical state of the basin's rivers, riparian habitat, and ground water. It will also serve as a demonstration of public commitment to improve the quality of life in the basin. The Consortium, under the leadership of Julie Stephens, Consortium member, has solicited numerous activities and events by Albuquerque teachers, Pueblo associations, and government agencies, including water travel ceremonies, Rio Grande seminars, bosque bird-watching trips, river clean-up events, and poster exhibits. *Dia del Rio* was designed as an annual event to be held the third Saturday of every October.

FUND RAISING

Janelia Grant.

A $5,500 proposal to cover the salary of Chris Nunn to serve as the newsletter editor of *La Corriente* was funded to UNM Natural Resource Center (Lee Brown, Director) in 1994.

Gauntlett Foundation Grant.

A $60,000 proposal for planning the February 1994, SDI conference, including funding for facilitators, subgroups, and salary for the workshop coordinator received a favorable review; however, the foundation dissolved prior to the award.

General Service Foundation.

A $25,000 grant to assist the Consortium's participation in the SDI Conference and provide

for a Basin-wide preconference planning meeting was obtained from the General Service Foundation. The planning session was held in Albuquerque on February 13-15, 1994.

Ford Foundation.

A $100,000 award for additional funding for SDI-related activities was awarded by the Ford Foundation, based on the success of the *Uniting the Basin* conference. Some of this money was channeled to all five of the Basin subgroups. Amigos Bravos received the funds to facilitate the *Dia del Rio* celebration in the Upper Basin, and the Consortium received $2,500 to sponsor and solicit events in the middle Rio Grande reach, including the Albuquerque area and surrounding Pueblos.

LITERATURE CITED

Crawford, C.S.; Cully, A.C.; Leutheuser, R.; Sifuentes, M.S.; White, L.H.; Wilber, J.P. 1993. Middle Rio Grande ecosystem: Bosque biological management plan. U.S. Fish and Wildlife Service, Albuquerque, NM. 291 p.

Houston Advanced Research Center. 1994. Uniting the Basin. The Rio Grande/Rio Bravo Basin Sustainable Development Conference. Conference Statement. HARC Center for Global Studies, Woodlands, Texas. 37 p.

Stone, W.; Minnis, M.; Trotter, E., Compilers. 1991. The Rio Grande Basin Global Climate Change Scenarios. Proceedings, Workshop/Conference June 1-2, 1990, Albuquerque, NM. Water Resources Research Institute, Las Cruces, NM. WRRI Report No. M24. 126 p.

Rio Grande Valley State Park maintenance, improvements, and developments

Tony Barron[1]

Abstract.—Managing the Rio Grande Valley State Park as a valued riparian-wetland area is very important as it encourages conditions for the growth of vegetation. This growth supports a riparian community consisting of various insects, animals, birds, and fish, as well as other wildlife. Human activity in riparian areas has led to historic use patterns causing erosion, re-location of animals and birds, and a loss of some valued riparian ecosystems. Riparian areas on the urban edge present a unique management challenge and opportunity. All area residents benefit from a properly functioning riparian/wetland environment. This paper deals with the issues of managing riparian areas. Riparian area managers must consider all concerns when balancing uses of riparian habitat from preservation of archaeological and cultural resources to riparian recovery, improvement, and development.

Managing the Rio Grande Valley State Park as a valued riparian-wetland area is very important as it encourages conditions for the growth of vegetation. This growth supports a riparian community consisting of various insects, animals, birds, and fish, as well as other wildlife. Human activity in riparian areas has led to historic use patterns causing erosion, re-location of animals and birds, and a loss of some valued riparian ecosystems. Riparian areas on the urban edge present a unique management challenge and opportunity. All area residents benefit from a properly functioning riparian/wetland environment.

Often the need for humans to access or traverse riparian areas are prevalent issues. Activists and other special interest groups exercise their interest and participation on their respective adoptive concerns. However, the riparian area managers must consider all concerns. These considerations range from the preservation of archeological and cultural resources contained within the riparian communities and ecosystems, including historical uses, and riparian recovery improvement and development issues.

American Disabilities Act accommodations should be provided to recreational areas as practical.

A program detailing additional clean up and recovery area by areas should be adopted. Some areas might be targeted as special projects to expedite recovery and stimulate management efforts.

ENFORCEMENT

Frequent patrols conducted by qualified and certified Law Enforcement personnel benefit recovery efforts. Enforcement serves as an educational tool as well as a deterrent.

The Open Space Division has maintained a law enforcement presence along the boundaries of Rio Grande Valley State Park since the mid 80's. Their on going presence along with the Albuquerque Police Department and Bernalillo County Sheriffs

[1] *Operations Manager, City of Albuquerque, Park & General Services Department, Open Space Division, P.O. Box 1293, Albuquerque, NM 87103.*

Department and other agency co-operators help make access and recreational opportunities safer than ever before.

MAINTENANCE

Maintenance of riparian areas requires the application of techniques to recover and restore areas affected by roads and other mitigation measures. Appropriate mitigation agreements should include restoration of trees and the desired plant community including a monitoring program. In addition funding should be provided for access improvements to facilitate timely response to wildfire, tree trimming, turn-around areas, and bosque access. Proper mitigation agreements along with sound riparian management practices are the most effective efforts to be considered when establishing multi-use recreational areas. Local governmental agencies as well as community support are vital components to insure necessary funding in and the implementation of riparian management goals for these valued riparian areas. Improvements should be planned by area, giving consideration to historical use patterns, physical and biological management considerations and limited recreational needs.

As areas are approved for improvements such as re-establishing degraded riparian areas and park facility remodeling and maintenance, proper funding should be provided for initial project improvements and on going maintenance, visitor service and law enforcement support. Resource managers and planners are strongly encouraged to review work loads presently being performed by administrative and clerical personnel. Additional services and training may be required. Ideally, given proper training, existing personnel can then be qualified and used for the job requirements. Additional training and salary adjustments are a much easier and cost-effective method of accomplishing riparian management goals and objectives utilizing existing personnel.

DEVELOPMENT

A. Developing recreational areas that reduce or filter noise will increase visitor enjoyment and reduce stress on the riparian community.

B. Designs should not include vehicle access to ditches and the river. Designs should not include areas in the 100 year flood plain.

C. If possible, design areas should be outside riparian areas and should be accessible for day use only.

D. Handicap accessibility should be provided where practical.

E. Mitigation standards should be established with governmental agencies and its co-operators.

F. Fencing should be installed in sensitive and protected areas.

G. A reforestation or recovery program should be an integral part of sound management practices. Adequate personnel will be required.

H. Adoption of an interpretation program should include signage and information centers designed to reduce vandalism and educate visitors to authorized access areas.

I. Trail and facility use control measures should be established. Activities reducing stress on wild life and other visitors also need to be considered.

J. Emphasis must be given to a responsive law enforcement section and the required support. Maintenance, improvements, developments and law enforcement all go together for successful management of multiple use riparian areas. If a presence cannot be maintained utilizing proper maintenance and/or law enforcement personnel then development of new sites is not recommended. Existing sites that are not funded or managed properly should be closed until funding, proper management and/or personnel are in place.

The citizen volunteer

Richard Becker[1]

Abstract.—This presentation will be a "reflective story" of a personal transformation that began at a dinner discussion in Antigua, Guatemala, with a BLM wildlife biologist, while on vacation. Classic literature cited in this evening conversations included *Cadillac Desert* and *A Sand County Almanac*. This introduction provided the door of awareness and opportunity for one person to become a "regular" volunteer with the BLM, USFS, and the New Mexico Department of Fish and Game.

Citizen organizations and their volunteers provide substantial resources to land management agencies which include volunteer time, effort and money. Through their assistance, habitat improvement projects are completed. Volunteers, likewise, benefit from the experience. A sense of "stewardship" evolves through this process.

The mutual benefits to both agencies and volunteers will be outlined in an effort to further promote the recruitment and retention of citizen volunteers.

Today, as we participate in this symposium, we bring with us a wide range of education, experiences and expectations. Some of us have lived through several decades of social change and changing public policy. We are looking to the next century, just a few years away. Whether we look to the future with certainty or doubt, be assured, it is on its way.

To me, as a citizen volunteer, I see in the present and in the future, the *necessity* of partnerships between land management agencies and volunteer citizen organizations.

Many agencies and volunteer groups recognize their mutually beneficial relationship and tend to measure the benefits in terms of dollars saved in the cost of projects by acquiring donated labor from involved citizenry.

While this is certainly true, I come today to add to this perception some additional thoughts about citizenship and volunteering.

How do we come to see ourselves as "citizen?"

Who, what and how do we define "citizenship?"

Can we say that this "social identity" is *conferred* upon us at birth, as in:

"You are a citizen of the U S of A by birth."

Yet this social designation has to be *assumed* or *taken on* by being involved in our social arenas, i.e., our families, our employment, our worship, our communities.

How often have we been led to believe that *voting* in public elections is the highest expression of our acting on our citizenship? While participation in elections is vital to the survival of our democracy, far too many people do not vote and of those who do, precious few get further involved in areas where volunteering public participation is needed.

As we move into the next century, can all of us promote the notion that *citizenship* and *stewardship* are connected concepts? Do we, as a Nation, and as a citizenry, really understand *governance*?

VOLUNTEERING

To be a volunteer is to be a person who offers himself or herself for a service or undertaking of his own free will with no promise of compensation; to give of one's time or resources for charitable, educational or other worthwhile activities, especially one's community.

[1] *President, ABQ Wildlife Federation, 1005 Indiana Street S.E., Albuquerque, NM 87108.*

Take a moment to reflect on your own experiences of being a "volunteer":

- serving on a PTA at school for your child;
- giving someone a ride in an emergency;
- collecting Toys for Tots;
- writing a letter for a friend.

A favorite bumper sticker of mine refers to RANDOM ACTS OF KINDNESS. No doubt you have helped others and others have helped you when you needed it.

In the last few years I have been learning how people-projects enhance our wildlife resources. My own experience in volunteering, especially on wildlife-related habitat projects, through the ABQ Wildlife Federation, has been a true learning experience.

For nonwildlife trained citizens, spending time "in the field" has become part of the "university of life experiences." For these experiences I am truly thankful.

I have observed open discussions between natural resource agency personnel in the USFS, BLM and citizen volunteers. These dialogues have provided insights into the complexities of issues and decisions facing these agencies.

These experiences have heightened my awareness of the debates over major public policy considerations, land management practices, formulation of endangered species recovery plans, definitions of wetlands, sources of nonpoint pollution, and new understanding about CRP (Conservation Reserve Program), North American Waterfowl Management Plans, CITES (Convention on International Trade in Endangered Species).

Many of us "citizen volunteers" were not trained to "Think Like a Mountain," in our university or graduate school curriculum.

We have been introduced to a new mix of words:

- Ecosystem;
- Stake holders
- Riparian
- High water events
- Habitat

Many of us had never heard of Aldo Leopold's *A Sand County Almanac*, Marc Reisner's *Cadillac Desert*, or Edward Abby's *Desert Solitaire*, until we met some of you. You have become partners in our post graduate field instruction of evolving citizen volunteers.

On a personal note, I quite accidentally first learned of *Cadillac Desert* while enjoying a dinner in Antigua, Guatemala with a BLM wildlife biologist on vacation. Coming from the Southwest, I found myself embarrassed at not knowing about this publication. I finally found a used copy of the book, and I was most amazed to learn the history of water developments in the West. I have since talked to many folks who, like me, had never read this classic, nor Sand County Almanac.

So, why am I giving you a presentation on the Citizen Volunteer? Why am I encouraging you to solicit volunteers in your agency programs and work projects? Here are some of my reasons:

1. I have heard agency personnel give facts and figures as to the amount in dollar terms, and that volunteers contribute to the success of an agency in meeting its goals and objectives. Volunteer labor was needed because no funds were available to pay for the work to be done.

   As a volunteer I am pleased to know that my contribution did make a difference. My own personal *reward*, however, was in *being a part of it*; part of the planning, execution, monitoring and understanding the potential long term benefit for "all those critters out there!"
2. Through volunteer activities, citizen volunteers and agency personnel can help each other understand the issues, how decisions are made or not made, and what the limitations are.
3. These interactional opportunities enable citizen volunteers to respect public servants in land management agencies who have devoted their careers to enhancing our forests, rivers, prairies and cultural heritage.
4. Finally, citizen volunteers are able too more thoroughly educate others as to the "good" that government agencies and their personnel do while "talking shop," having a beer at a bar-b-que, or riding on an airplane reading Aldo Leopold's Essay, "Thinking Like a Mountain."

In a culture that promotes conflict and adversarial relationships, citizens need opportunities to experience team work and collaborative relationships which you provide in any number of ways.

KEEP UP THE GOOD WORK!

Riparian wetlands and visitor use management in Big Bend National Park, Texas[1]

C.M. Fleming[2], S.H. Kunkle[3], and M.D. Flora[4]

Abstract.—Wetlands and riparian habitats constitute a small, but nonetheless vital component in the Chihuahuan Desert. Big Bend National Park, 801,000 acres, contains about 27,000 acres of wetland. The park has riparian or wetland habitat distributed around 315 water sources, some perennial streams, and along 118 miles of the Rio Grande. These areas contain unique vegetation components, which provide habitat for wildlife, including resident and migratory birds, and support other wildlife. The same habitats have become increasingly popular as overnight campsites for rafters and boaters on the Rio Grande, or serve as water stops and destination points for backcountry hikers and campers.

Resource impacts, resulting from careless use and overuse, has been documented by several surveys at a number of the more popular areas. This presentation discusses these impacts and the park management actions which are underway or under consideration to deal with them. The management actions are aimed at limiting resource damage to wetland and riparian habitats while permitting visitor use of the resources.

INTRODUCTION

Big Bend National Park, with 801,000 acres, is the eighth largest park in the continental United States. The park is located in southwestern Texas, at the "Big Bend" of the Rio Grande, and lies adjacent to the Mexican States of Chihuahua and Coahuila. Big Bend National Park contains about 27,000 acres of wetland and riparian habitat.

Wetlands and riparian habitats constitute a small, but nonetheless vital, component in the Chihuahuan Desert. Wetlands and riparian habitats are not only sensitive areas in Big Bend National Park but also are habitats attractive to campers, rafters, boaters, and hikers. The 118 mile reach of the Rio Grande along the southern boundary of the park is the park's popular rafting zone. This stretch of the Rio Grande also supports riverine habitats not frequently found in the Chihuahuan Desert environment, which therefore are critical sites for birds, wildlife, and certain Chihuahuan plant species. The park contains some 315 water sources and several tributary streams, which also are subject to impacts by hikers, off-road travelers, and campers.

The park's wetland and riparian habitats are highly sensitive to the impacts of recreationists. This presentation summarizes the nature of these impacts —with emphasis on the recreational aspects— and reviews some of the management actions underway in the park that aim to limit resource damage while still permitting visitor use of the resources.

[1] Panel Topic on "Determining and Responding to Human Needs and Desires".

[2] National Park Service, Bend National Park in Texas.

[3] National Park Service, Southwest System Support Office in Santa Fe, New Mexico.

[4] Water Resources Division in Denver, Colorado.

IMPACTS AND ISSUES IN THE PARK

Recreation in the park

Big Bend National Park serves the dual purposes of preserving resources and simultaneously providing for recreation. Floating the river is a popular recreational activity in the park. For example, in 1992 about 6000 people took commercially-guided raft trips and about 4700 took private river trips on the Rio Grande. The number of *commercial* river boating and rafting permits has been relatively stable since 1984, fluctuating between 700 and 900 permits annually. Since 1988, *private* permits have declined and are now generally fewer than the numbers of commercial permits. Commercial outfitters consistently have more people per boat than do private permittees. Roughly half the permits issued are for day trips, and half for overnight trips (Stewart et al., 1993).

Overnight river trips naturally include camping. According to a recent assessment by Williams and Marion (1995), Big Bend National Park has 268 back country campsites in total, including 54 along the Rio Grande accessible from the river. In total, 75 campsites are found near the Rio Grande, including those accessible by a riverside road. In terms of river camping capacities, the Williams and Marion assessment determined that 21 of the river-accessed river sites can accommodate 1-2 boats, 20 up to 3-4 boats, and 13 more than 5 boats camping at a time.

Recreational impacts along the river

Camping and other recreational activities occurring along the river affect riparian natural resources. For about two decades the park has been observing these growing impacts in beaches, campsites, streambanks, access points, channels, and riverside woodlands along the river and monitoring the changes in vegetation, fauna, and other aspects. The following human-caused disturbances are common along the river:

- littering
- trampling
- rock moving
- campfire effects
- accidental fires
- human waste
- wood cutting
- vegetation disturbance
- exotic plant introduction

These various impacts work in conjunction and are cumulative, and lead to modified habitats and less biological diversity. The park has verified through studies that plant communities have been changing over the decades (Schmidly and Ditton, 1977 and Hughes et al., 1993).

Research has shown that fires initiated by recreationists near the river dramatically affected woody scrub over wider areas, beyond the riparian strip. After fire, wood scrub in the Chihuahuan Desert community normally takes many years to return to its pre-fire habitat.

Away from the river, springs serve as a water source and attraction for 54 campsites in the park. Intense use of these areas leads to many of the same impacts listed for the riverine area, including soil compaction, pollution, littering, and erosion.

Impacts from livestock grazing

Any recreational impact study must attempt to separate out "non-recreation" effects, such as grazing and flooding. In Big Bend National Park, trespass livestock come across the border from Mexico, causing serious grazing pressure in some areas. They alter the vegetative cover, introduce exotic species, change plant species composition, add nutrients, and physically trample the riverine areas, inciting erosion. Of course manure can affect water quality and introduce contaminants into the river.

Cattle also graze on trees and other sprouts, thereby reducing natural vegetative regeneration. For example, cattle prefer to feed on native cottonwood sprouts, and not exotic *Tamarix* (salt cedar) seedlings, thereby enhancing the opportunity for *Tamarix* to take over grazed riparian habitat. As vegetative cover changes, the composition of wildlife, birds, rare animal species, and other faunal aspects of the ecosystems follow suit, until eventually a less diverse, poorer habitat has replaced the original ecosystem. Studies of plants and animals along the river have demonstrated the degradation in biological diversity occurring over the past two decades (Hughes et al., 1993).

Impacts related to flooding

At certain times of the year, virtually all of the river's discharge comes from the Rio Conchos in

Mexico (University of Arizona, 1995), and at these times the park has no influence on stream discharge levels or their fluctuations. The Rio Conchos flows into the Rio Grande about 59 miles upstream from the park boundary. River levels in the park are affected by unpredictable water releases from the Luis Leon Dam on the Rio Conchos as well as by intense local storms. These irregular streamflows influence erosion, sedimentation, meandering, and other physical processes in the river channel and riparian area. Riverine biota ultimately are affected by these physical changes. In summary, erratic river flows in the park present a serious threat to the flora and fauna that depend on the unique niche provided by the Rio Grande riparian corridor (Hughes et al., 1993). As with livestock grazing, it is not easy to separate out recreational impacts from the significant effects of flooding along the river.

MANAGEMENT ACTIONS AND RECOMMENDATIONS

The park has a number of actions either underway or planned with a view to reducing the impacts of recreational activities and grazing on the riparian and wetland areas in the park. The following activities or proposals by the park relate to recreational impacts.

- Soon the park will complete its River Use Management Plan and a Water Resources Management Plan. The River Use Management Plan will help park managers understand the extent of recreational pressures at various seasons and provide an assessment of the "demand" on the river. It also will provide information on the essential role of a permit system.
- The Water Resources Management Plan will provide essential data and information on such issues as flooding, water quality, and upstream water releases. This report will provide the water resource database and hydrologic tools that park managers need to better monitor and predict river discharge, water quality, floods, and droughts. This is essential background information for planning water-based recreation in the park and for managing recreational impacts in the riparian areas.
- The park also is seeking closer ties with Mexican authorities, the International Boundary Waters Commission (IBWC), the Rio Grande Compact Commission, and other upstream authorities, in order to better understand the river management upstream to better predict flows coming in from the Rio Conchos and Rio Grande. This cooperation should allow better prediction of park flow conditions, thereby providing a better basis for the park's planning and management of recreation along the river.
- The park is seeking to adopt an equitable river permit process to better track and manage use levels.
- An advanced reservation system for river use permits is currently not in effect, but is a possiblity if future use levels warrant.
- The park now encourages backcountry visitors to carry all their own water —to avoid impacts on backcountry springs. When recreational information is provided to visitors, spring location is not "advertised," to reduce impacts on these sites. The park advises all visitors to boil or treat water from backcountry sources.
- Camping in the backcountry is now by permit only, to better control those impacts. In some cases gates and fences are designed to reduce impacts on springs or other sensitive areas.
- Within future budget and time constraints, the park also is considering the following possibilities: restricting campsites along the Rio Grande; placing limits on numbers of individuals to use a specific campsite (via permits).

REFERENCES

Ames, C.R. 1977. Wildlife conflicts in riparian management: grazing. pp. 49-51 *In* Proceedings, Symposium on Importance, Preservation, and Management of the Riparian Habitat, Tucson, Arizona, July 9, 1977.

Big Bend National Park. 1995 (in progress). Draft Backcounty Management Plan and Environmental Assessment. Office of Science and Resources Management, Big Bend National Park, Texas 79834. 120 pp.

Big Bend National Park. 1995 (in progress). Draft River Use Management Plan and Environmental Assessment. Office of Science and Resources Management, Big Bend National Park, Texas 79834.

Davis, G.A. 1977. Management alternatives for the riparian habitat in the Southwest. pp.59-66 *In* Proceedings, Symposium on Importance, Preservation, and Management of the Riparian Habitat, Tucson, Arizona, July 9, 1977.

Hughes, B.G., K.J. Mickey, J.F. Scudday, and A.M. Powell. 1993. A reanalysis of recreational and livestock trespass impacts on the riparian zone of the Rio Grande, Big Bend National Park, Texas. Report to the National Park Service, Southwest Region, Santa Fe, NM. 144pp.

Kennedy, C.E. Wildlife conflicts in riparian management: water. pp. 52-58 *In* Proceedings, Symposium on Importance, Preservation, and Management of the Riparian Habitat, Tucson, Arizona, July 9, 1977.

Schmidly, D.J., and R.B. Ditton. 1977. A survey and analysis of recreational and livestock impacts on the riparian zone of the Rio Grande in Big Bend National Park. Department of Wildlife and Fisheries Sciences and Department of Recreation and Parks, Texas A&M University. Report for the National Park Service. Big Bend NP. 159pp.

Stewart, W.P., B.S. Anderson, and P.S. Dunfee. 1993. A user study of the Rio Grande river corridor in Big Bend National Park. Final report for Big Bend National Park (CA 7029-1-0013). Department of Recreation, Park and Tourism Sciences. Texas A&M University, College Station. 149pp.

University of Arizona. 1995. Draft underway for a Water Resources Management Plan; Big Bend National Park. Personal communications with Robert MacNish, University of Arizona.

Whitson, P.D. 1974. The impact of human use upon the Chisos Basin and adjacent lands. National Park Service Scientific Monograph Series. Number 4. NPS 117. (Supt. of Docs. no. I 29.80:4). 92pp.

Williams, P.B. and J.L. Marion. 1995. Excerpts from draft report on "Assessment of backcountry campsite conditions in Big Bend NP" (Personal communication with J.L. Marion, Virginia Tech, Blacksburg, VA, July, 1995).

The Arizona Riparian Area Advisory Committee: An experience in defining desired conditions

K.E. Randall[1]

Abstract.—Created in 1992 by the Arizona Legislature, the Riparian Area Advisory Committee (RAAC) developed recommendations for protecting, maintaining, and restoring riparian areas in Arizona. These recommendations were submitted to the Legislature and to the Governor after concluding a two year period of study and discussion. The RAAC, consisting of 34 members broadly representative of federal and state agencies, tribal government, counties, municipalities, major economic resource user groups as well as environmental and recreational organizations, agreed on a Conservation Goal and on the broad outlines of a riparian area protection strategy that took a watershed approach. The adopted Conservation Goal was to sustain and enhance Arizona's riparian areas by managing land, water, and resource uses to protect ecological integrity and functionality. RAAC recommended that cooperative efforts with local, state, federal governments and Indian tribes in the protection, maintenance and enhancement of riparian areas be encouraged. Direct involvement of local groups and citizen participation would be a cornerstone of these efforts. Riparian protection solutions should be unique to the circumstances of each area of the state. At the present time, the submitted recommendations have not resulted in changing any existing state regulatory authorities.

INTRODUCTION

The need to develop riparian area protection for the State of Arizona has been identified as an important issue. State efforts on this issue have been on-going since 1985. Previous studies include the 1986 *Arizonans Recreation Needs on Federal Lands*, the 1988 *Arizona Wetlands Priority Plan* (addendum to the 1983 SCORP), the 1988 *Report of the Commission on the Arizona Environment*, the 1989 *Statewide Comprehensive Outdoor Recreation Plans* (SCORP), and the 1990 *Final Report and Recommendations of the Governor's Riparian Habitat Task Force*. Governor Rose Mofford issued Executive Order 89-16, *Streams and Riparian Resources*, of June 10, 1989, and Executive Order 91-6, *Protection of Riparian Areas*, of February 14, 1991 to address this important state issue. She also created the Governor's Riparian Task Force, which issued its report in 1990. Other studies include *The Interrelationship Between Federal and State Wetlands and Riparian Protection Programs* (Steiner, et al. 1991) and *Analysis of Water Quality Functions of Riparian Vegetation* (Engineering-Science, Inc. 1994).

In an effort to resolve the public debates and the many issues that surround riparian areas, the Arizona legislature passed a Riparian Area Act in 1992 which amended Arizona Revised Statute (ARS) 45-101. This paper discusses three components of that act.

One component directed three state agencies to study various aspects of riparian areas. The second component formed and directed the activities of the Riparian Area Advisory Committee (RAAC).

[2] *Riparian/Wetland Coordinator, Nonpoint Source Unit, Arizona Department of Environmental Quality, Phoenix, AZ.*

The third component was the final recommendations for protecting, maintaining, and restoring riparian areas developed by RAAC which were submitted to governor and legislature.

COMPONENTS OF THE 1992 RIPARIAN AREA ACT

In passing the Riparian Area Act, the legislature debated on an appropriate definition for riparian areas and decided to define riparian areas to mean "a geographically delineated area with distinct resource values, that is characterized by deep-rooted plant species that depend on having roots in the water table or its capillary zone and that occurs within or adjacent to a natural perennial or intermittent stream channel or within or adjacent to a lake, pond, or marsh bed maintained primarily by natural water sources. Riparian area does not include areas in or adjacent to ephemeral stream channels, artificially created stockponds, man-made storage reservoirs constructed primarily for conservation or regulatory storage, municipal and industrial ponds or man-made water transportation, distribution, off-stream storage and collection systems."

The Riparian Act called for three state agencies to collect scientific and economic data on riparian areas in the state of Arizona. Reports were to be submitted to the Governor, the legislature, and the Riparian Area Advisory Committee (hereafter referred to as RAAC). RAAC was a legislatively formed committee called in order to make recommendations to the legislature concerning protection of riparian areas.

Scientific data were collected and analyzed by three State agencies. The Arizona Game and Fish Department classified and mapped riparian areas along perennial stream reaches (Valencia, et al. 1993). Mapping efforts are continuing for intermittent streams.

The Arizona Department of Water Resources (DWR) evaluated the hydrologic effect of groundwater pumping and surface water appropriations on riparian areas (Arizona Department of Water Resources 1994 a,b,c,d). Surface water law and groundwater law are separate in Arizona. For this evaluation DWR used case studies of three perennial rivers in the state; Verde River, San Pedro River, and the Santa Cruz River. Additionally, DWR also evaluated alternative regulatory programs designed to balance the protection of riparian areas with existing and future groundwater pumping and new surface water appropriations and changes in the use of point of diversion of existing surface water appropriations.

The Arizona Department of Environmental Quality (Arizona Department of Environmental Quality 1993) assessed the impact of 12 land use activities that occur on land in riparian areas in the state that involve removing or depositing material, removing vegetation or otherwise obstructing, altering or destroying riparian areas. The activities evaluated were:

- Timber harvesting
- Agricultural land clearing
- Recreational use and development
- Commercial, industrial and residential development
- Road and bridge construction
- Dam and reservoir construction and operation
- Channelization and bank stabilization
- Sand and gravel extraction
- Wetland drainage
- Grazing
- Landfills and sewage treatment facilities
- Mining and metallurgical operations.

These reports were provided to members of the RAAC to report on the status and condition of Arizona's riparian areas and the impact human activities have had. The committee was comprised of 34 people representing varied interests in riparian area issues. The 19 members appointed by the governor represented industry such as cattle growers, timber, agriculture, and sand and gravel. Also included were environmental organizations such as The Nature Conservancy, Native Plants Society, and Audubon. A river runner represented recreational users. One person served as the sole representative of the Indian nations in the state of which there are 22 separate and sovereign tribal governments. Seven of the members represented state agencies. Coordination with existing federal programs was recognized as important, and eight members from federal agencies were represented as *ex officio* members.

RAAC began meeting in November 1993. After gathering background information on riparian areas, they began to assess alternative regulatory and nonregulatory strategies to protect riparian areas. An interim report of these findings was submitted to the legislature in July 1994. Final recommendations were developed and submitted to the legislature in December 1994 outlining the statutory provisions for a riparian area protection program in the state.

OUTCOMES OF THE INTERIM REPORT

To facilitate the analysis of existing state and federal regulatory and nonregulatory programs in Arizona and in other states and development of alternative regulatory and nonregulatory strategies, the RAAC identified committee and conservation goals and guidance principles.

Committee goals

1. Identify the kinds of measures that may be needed for a riparian area protection program in Arizona.
2. Assess alternative regulatory and non-regulatory strategies with an analysis of the fiscal, economic and environmental impacts of each, and consideration of different alternatives for different classes of landowners.
3. Evaluate the agency reports directed in the legislation.
4. Recommend a comprehensive strategy for the conservation and enhancement of Arizona's riparian areas including proposed statutory provisions.

Conservation goal

To sustain and enhance Arizona's riparian areas by managing land, water and resource uses to protect ecological integrity.

Guiding principles

1. The best available scientific and technical information should form the basis for riparian area management decisions.
2. Cooperative and consultative approaches to decision-making and action should be employed.
3. Full consideration of environmental, social and economic costs and benefits should be a part of decision-making.
4. There should be regulatory and non-regulatory measures as part of a comprehensive plan.
5. The legal rights of the private property owners must be respected.
6. The spirit of State Executive Orders 89-16 *Streams and Riparian Resources* and 91-6 *Protection of Riparian Areas* will serve as guidance for development of recommendations by the Committee.

Early during one of RAAC's meetings, a brainstorming session was held in which members discussed and identified current threats to riparian areas and what future desired conditions for riparian areas should be. Five major issues and their associated activities that impact riparian areas were identified by RAAC (table 1). These issue areas focused upon causes of damage to riparian areas and possible solutions. Identification of these issues assisted RAAC in developing various regulatory and nonregulatory strategies for protecting, maintaining, and restoring riparian areas.

Existing programs in Arizona and in other states can be better understood by determining how they address these issues through either regulatory or by nonregulatory methods. The cost of dealing with some issues may be greater than the benefits. Regulatory programs at the state and federal levels that address these activities through regulatory measures, policy statements, or management plans were identified in a matrix format. This matrix is attached as an appendix.

The level of protection to riparian areas a regulation offers was identified for particular regulations. Very few laws and regulations were rated as 3. This rating indicated that the regulation directly or indirectly addressed riparian areas or where specific examples in Arizona were known that these laws and regulations have been used and generally offer high protection. Equally limited were laws and regulations that have the potential to protect but implementation or results have not

Table 1. **Major Issues that affect riparian areas in Arizona and possible solutions.**

Issues	Possible solutions
1. Water Availability	
Groundwater pumping depletes surface water flows, or lowers water table below root zone	Limit pumping amount; limit withdrawal from certain areas; incentives to switch to other water sources or deeper aquifers; require groundwater replenishment; education; water conservation to reduce demand; mitigation in another area
New surface water diversions or changes in current diversion points reduce stream flows	Purchase and retire water rights; instream flow rights; better court protection of existing downstream rights; limit new diversion; permitting for changing point of diversion; water conservation to reduce demands; incentives to use other sources; mitigation in other areas
Reservoir release patterns affect seasonal availability disrupt flood cycles	Mitigation; incentives to change release patterns; negotiated permits and operating criteria
2. Large-scale destruction or alteration of river channels	
Sand and gravel mining; placer mining	Best Management Practices (BMPs); exclusion from some areas; reclamation requirements; mitigation measures; impact assessments
Dredging and filling	Best Management Practices (BMPs); exclusion from some areas: reclamation requirements; mitigation measures; impact assessments
Landfills	Best Management Practices (BMPs); exclusion from some areas; reclamation requirements; mitigation measures; impact assessments
Road construction	Best Management Practices (BMPs); exclusion from some areas; reclamation requirements; mitigation measures; impact assessments
Channelization and bank stabilization	Improved benefit/cost studies; impact assessments; flood plain management and zoning; compensation/incentive programs for adjacent landowners; exclusion from certain areas
Inundation caused by new reservoir construction	Improved benefit/cost studies; impact assessments; mitigation; exclusion from certain areas; water supply or flood protection alternative
3. Adjacent land uses (erosion, sedimentation, vegetation change, water quality impacts)	
Grazing	Permitting with BMPS on public lands; BMPs on private land; fencing; incentive programs for riparian improvement; incentives to develop alternative water sources; exclusion from some public lands
Timber harvesting	BMPs; require buffer strips; exclusion from special areas; incentives for buffer strips
Agriculture	BMPs; require buffer strips; exclusion from special areas; incentives for buffer strips
Mining	Impact assessments; BMPs; reclamation requirements; require bonds posted to ensure cleanups and compliance; large buffer zones
Road construction	Impact assessment; benefit/cost assessment; alternative rout selections; BMPs; reclamation requirements; buffer zones
Commercial/residential/industrial development	Zoning; construction setbacks; buffer strips; BMPs; incentives for conservation easements; government purchase of special areas

(Cont'd.)

Table 1. Continued

Issues	Possible solutions
Degradation from recreational uses	Quota; reservations for certain areas; improved trails; facilities; closing some access points; limitation of off-road vehicle use; education
4. Point Source water quality problems	
Effluent from sewage treatment plants	NPDES permits; improved monitoring and enforcement; improved secondary or tertiary treatment; government grant/loans for treatment plant upgrades; special standards for effluent dominated waters; pre-treatment programs; effluent reuse or recharge
Pollution from industrial and other point sources	same as above
5. Exotic (non-native) species	Eradication programs; stocking and planting programs; prescribed burning

been seen in Arizona. These were defined as offering moderate protection and rated 2. The majority of the laws and regulations address riparian areas through management plans, policies, and technical assistance. These generally offer low or incidental protection and were rated 1. Laws and regulations that offer no protection were rated 0. Many regulations were thought to address riparian areas but after analysis it was determined that did not. These regulations were left blank.

OUTCOMES OF THE FINAL REPORT

The information in the Interim Report was utilized by RAAC in preparing the Final Report. The RAAC reached broad agreement that there needs to be a local riparian planning process that incorporates state and other interests to achieve the Conservation Goal. The Committee further agreed that there needs to be some mechanism to bring people to the table, and there should be a balance of power between state and local governments in the planning process and all stakeholders should be included in the planning process to achieve the Conservation Goal.

The approach to riparian planning, methods for convening a local riparian planning process, the local, state, tribal, and federal roles in such a process, and the currently available authorities that could be used for planning purposes are described as follows. The creation of local riparian planning councils would be either locally or legislatively initiated. These councils would be broadly representative of the local, state, tribal, and federal agencies affected by riparian decisions as well as of the various resource user and citizen groups with a stake in the future of riparian areas. These councils, defining a study area in terms that is locally meaningful, would produce a plan in a two year period to achieve goals of local definition. By taking advantage of authorities already available to existing agencies, the councils could help produce Intergovernmental Agreements that would be the mechanism for implementing planning goals.

The state would participate in such councils and would also create a Coordinating Council. Consisting of the Arizona Department of Environmental Quality, the Arizona Department of Water Resources and the Arizona Game and Fish Department, the Coordinating Council would provide technical assistance and other support to the local riparian councils. Technical assistance in restoring, maintaining, and restoring riparian areas has received significant attention. There is a need to assist land owners in the permitting process, analysis of riparian functions, advise on best management practices, funding assistance, and information exchange.

This Coordinating Council would use the riparian mapping and inventory information prepared by the Game and Fish Department to assess riparian areas on an on-going basis. The Coordinating Council would be able to convene a local riparian planning process, one outcome of which may be

the formation of a riparian planning council, but would have no new authority to impose goals for riparian protection on local areas.

Riparian Planning Councils should make full use of the land and water management authorities that are available under state law. The current surface water authorities (no change to existing statutes) would allow the Riparian Planning Councils to perform hydrologic modeling studies to determine a threshold volume that could trigger additional programs. Until threshold volumes were reached, new uses could be treated like existing uses. Instream flow water rights could be established for specific perennial stream segments. The concept of conjunctive management of both surface and groundwater was proposed. One proposal was to provide incentives for use of alternate water sources that would not create a potential adverse impact on baseflow or riparian vegetation water needs. Another proposal was to develop a conservation program for all water users with technical assistance from the Coordinating Council.

The need to establish an education program to disseminate information regarding the needs of the riparian area and appropriate regulatory requirements for the affected and interested public and private groups and industries within the planning area was recognized as important. The need to develop information about the functional condition of riparian areas (using standard methodology) in order to assist in understanding how the riparian area operates and to implement proper management tools was also recognized as an important planning tool.

CONCLUSION

RAAC created a possible structure for riparian area planning. The unanimously agreed-upon structure identified that such plans need to be unique to the area, locally driven, provided with technical and financial assistance, and have minimal (to none) regulatory authority.

At the same time RAAC was developing its recommendations, a similar piece of legislation was drafted for Sierra Vista, a community in southeastern Arizona. The community of Sierra Vista has had a long debate on whether groundwater pumping is affecting the surface flow in the San Pedro River. Legislation was drafted to address the issue of water management planning. However, because of the political climate in 1994, neither RAAC's recommendations nor Sierra Vista's proposed legislation were ever introduced in the legislature.

Arizonans have long recognized the value of riparian areas to the State, and have sought ways to protect them that would not cause undue hardship or infringe on private property rights. The recommendations of RAAC were major steps toward addressing this issue in Arizona. However, at the present time, there remains no State regulations to protect and maintain riparian areas.

REFERENCES

Arizona Department of Environmental Quality. 1993. Evaluation of Activities Occurring in Riparian Areas. Phoenix, Arizona: Nonpoint Source Unit, Water Assessment Section.

Arizona Department of Water Resources. 1994a. Draft Riparian Protection Program Legislative Report: Summary of Findings. Phoenix, Arizona.

Arizona Department of Water Resources. 1994b. Draft Riparian Protection Program Legislative Report: Volume A. Phoenix, Arizona.

Arizona Department of Water Resources. 1994c. Draft Riparian Protection Program Legislative Report: Volume B. Phoenix, Arizona.

Arizona Department of Water Resources. 1994d. Draft Riparian Protection Program Legislative Report: Volume C. Phoenix, Arizona.

Arizona State Parks Board. 1988. Arizona Wetlands Priority Plan: An Addendum to the 1983 SCORP. Phoenix, Arizona: Prepared by the Arizona State Parks Statewide Planning Section, in cooperation with Arizona Outdoor Recreation Coordinating Commission, Arizona Game and Fish Department, U.S. Fish and Wildlife Service, and National Park Service.

Arizona State Parks Board. 1989. Statewide Comprehensive Outdoor Recreation Plan (SCORP): Arizona Rivers, Streams & Wetlands Study. Phoenix, Arizona: Arizona State Parks.

Engineering-Science, Inc. 1994. Analysis of Water Quality Functions of Riparian Vegetation. Prepared for the Arizona Department of Environmental Quality. Phoenix, Arizona.

Folk-Williams, John and Kris Randall. 1994. Oral and Written Comments Recorded at Open House Meetings Regarding the Riparian Area Advisory Committee. Phoenix, Arizona.
Governor's Task Force on Recreation on Federal Lands. 1986. Arizonans Recreation Needs on Federal Lands. Phoenix, Arizona.
Governor's Riparian Habitat Task Force. 1990. Final Report and Recommendations of the Governor's Riparian Habitat Task Force.
Steiner, Frederick, Scott Pieart, and Edward Cook. 1991. The Interrelationship Between Federal and State Wetlands and Riparian Protection Programs. Prepared for the Arizona Department of Environmental Quality. Arizona State University Herberger Center, Tempe, Arizona.
Valencia, Ruth A., Jennifer A. Wennerlund, Richard A. Winstead, Scott Woods, Larry Riley, Eric Swanson, and Susan Olson. 1993. Arizona Riparian Inventory and Mapping Project. Phoenix, Arizona: Arizona Game and Fish Department.

APPENDIX FOLLOWS

Appendix. Key regulatory laws and regulations that apply to riparian areas

ISSUE AREAS vs. REGULATIONS	Groundwater Pumping	Surface water diversion	Water release patterns	Sand & gravel mining	Dredging & filling	Landfills	Road construction	Channelization & bank stabilization	Inundation by new reservoir releases	Grazing	Timber harvesting	Agriculture activities	Mining & Metallurgical Operations	Commercial/Residential/Industrial development	Recreational uses	Effluent discharges	Restoration
STATE																	
Clean Water Act, Sec. 401				3/2	3/2	3		3/2	1							3/0	
ADEQ Nonpoint Source Management Program				0	0	0	1/0	0		0	1/0	1/0	0	0	0		
Surface Water Quality Standards				3/0	3/0	3/0		2/0		1						3/0	
Arizona Native Plant Law				0	0	0		1/0						1/0			
Groundwater Management Act (1980)														2		0	
Groundwater Rights	2/0															0	
Groundwater Basin Transfer Law	3																
Groundwater Recharge Program																	
Effluent Regulation																	
General Surface Water Rights		2/1	2/1													0	
Instream Flow Rights		2															
Adjudication of Water Rights	2	2															
Water Right Sever & Transfer		2															

ISSUE AREAS vs. REGULATIONS	Groundwater Pumping	Surface water diversion	Water release patterns	Sand & gravel mining	Dredging & filling	Landfills	Road construction	Channelization & bank stabilization	Inundation by new reservoir releases	Grazing	Timber harvesting	Agriculture activities	Mining & Metallurgical Operations	Commercial/Residential/Industrial development	Recreational uses	Effluent discharges	Restoration
Executive Order 91-6		1		2	2	3/2	2	3/2		1	1		2	2	1		
Antidegradation Standards for surface water																	
Unique Waters Designation				3	3	3	2	3		1	3/2					3/0	
Aquifer Protect Permit													1	1		1/0	
Riparian Ecosystem Strategic Plan (1989) - State Lands Department					1			1					1				
State Land Mineral Leasing (ARS 27-251)													3				
ADOT Standards Specifications for Road & Bridge Construction						2/1	1										
Solid Waste Facilities					1	3											
State Land Code (ARS37-)										1	1	1					

ISSUE AREAS vs. REGULATIONS	Groundwater Pumping	Surface water diversion	Water release patterns	Sand & gravel mining	Dredging & filling	Landfills	Road construction	Channelization & bank stabilization	Inundation by new reservoir releases	Grazing	Timber harvesting	Agriculture activities	Mining & Metallurgical Operations	Commercial/Residential/Industrial development	Recreational uses	Effluent discharges	Restoration
FEDERAL																	
Clean Water Act, Sec. 404/ Sec. 10 Rivers & Harbors Act		1		2	3/2	3	2	3/2	2	0			3	3/2		0	
Wilderness Act					3		3/2	3		1/0			3/2		3		
Wild & Scenic River Act		2		3	2			3	2/0		2		2	2/0	3/2		
Endangered Species Act	3/2	3/2	2/1	3/2	3/2	3/2	3/2	3/2	2	3			3/2	3/2	3		
National Environmental Policy Act	2	2/1		1	2/1		2	2	2/1	2/1			2		2		
BLM Management Plans				2/1	2/1		2			3/2	3/2		2/1		1		
USFS Management Plans				2/1	2/1		2			3/2	3/2		2/1		1		
BOR Wetland/Riparian Policy				3/2	3/2	3	2/1	3/2	2/1						2/1	3	3
Clean Water Act, Sec. 402 (NPDES)							2/1	1/0					2	2		3/0	
Emergency Wetlands Resources Act							1										
Federal Reserved Water Rights	3/2	3/2															
Fish & Wildlife Coordination Act				2	2		2		2/0					2/0			
Surface Mining Control and Reclamation Act of 1977																	
Water Project Recreation Act									1								

ISSUE AREAS vs. REGULATIONS	Groundwater Pumping	Surface water diversion	Water release patterns	Sand & gravel mining	Dredging & filling	Landfills	Road construction	Channelization & bank stabilization	Inundation by new reservoir releases	Grazing	Timber harvesting	Agriculture activities	Mining & Metallurgical Operations	Commercial/Residential/Industrial development	Recreational uses	Effluent discharges	Restoration
National Historical Preservation Act					1/0			2									
Minerals & Materials Act, 1947				2/1											1/0		
Farmland Protection Policy							1										
Water Bank Act				2/1			2/1					2/1					
Department of Transportation Act							1										
Surface Transportation & Uniform Relocation Assistance Act							1										
Taylor Grazing Act										1							
BLM Range Regulations										3/2							
BLM Regulations 43 CFR 3809													1				
Public Rangelands Improvement Act (1978)										2							
Forest and Range Renewable Resource Planning Act (1974)				1	1					2	2						
U.S. Forest Service Manual										3/2	3/2				2/1		
U.S. Forest Service Organic Act										2	2						
Ft. McDowell Water Settlement Act			3														

Cooperative management of riparian forest habitats to maintain biological quality and ecosystem integrity

David Deardorff[1] and Kathryn Wadsworth[2]

Abstract.—The New Mexico State Land Office has initiated a rare plant survey of state trust land, an inventory and assessment of riparian areas on the trust land, and the development of a biological resources data base and information management system. Some riparian sites that still belong to the trust have been negatively impacted by livestock such that biological quality and ecological integrity of these sites have been reduced. Some sites on state trust land may have high potential for the development or restoration of riparian forests which could serve as essential habitats for neotropical migratory birds. The state land office is currently considering ways to manage trust land and restore riparian sites. This paper reviews potential solutions.

The New Mexico State Land Office manages some nine million surface acres of land in New Mexico on behalf of the beneficiaries of the trust, which primarily are the public schools. One statutory mandate of the trust is to maximize the revenue derived from the trust lands for the beneficiaries. The state trust land is not public land, it is analogous to private land, and, unlike federal land, does not have the same mandate of multiple use for the benefit of the American people as do our national forests and BLM land. Thus, throughout the history of the state land office, the primary emphasis of management of the trust has been revenue generation from a wide variety of activities including oil and natural gas development, livestock grazing, mining, rights of way, and commercial leases, among others. These activities have, over the years, resulted in a permanent fund of some four billion dollars.

A second mandate of the trust, however, is to preserve and protect the trust from waste and degradation and preserve the assets of the trust for future generations of schoolchildren. To that end, the State Land Office has initiated a rare plant survey of state trust land, an inventory and assessment of riparian areas on the trust land, and the development of a biological resources data base and information management system.

One constraint on the land office as manager of the trust is that none of the revenue derived from the trust may be used for improvements to the trust. Thus, the land office may not plant trees or grass seed or implement erosion control on state trust land. All such improvements must be carried out, if at all, using volunteer labor and donated materials, or using funds derived from sources other than the revenue from the trust.

A graphic example of the dilemma facing the managers of the trust is presented by state trust land in riparian forest habitats under grazing leases. Few such sites remain in the trust because most riparian forests, or bosques, with perennial water are now in private or federal hands. Of the few riparian sites which still belong to the trust, some have been negatively impacted by livestock grazing such that the biological quality and ecological integrity of the site have been compromised. For those sites which have been compromised, how may the situation be rectified, given that under the mandates of the trust: a) it is not

[1] *Biologist, New Mexico State Land Office, P.O. Box 1148, Santa Fe, NM 87504-1148.*

[2] *3 Aula Court, Santa Fe, NM 87505.*

desirable for the State Land Office to withdraw the land from grazing through an exclosure since that would interrupt the revenue stream from the land to the beneficiaries of the trust, and b) the State Land Office is not permitted to purchase or install plant materials, livestock water supplies, or fences for ecosystem protection or rehabilitation.

One of the consequences of the deteriorating condition of riparian forests which is becoming of increasing concern to land managers throughout the southwest is the precipitous decline of some species of neotropical migratory songbirds, many species of which use the Rio Grande corridor and its associated riparian forest, the Bosque, either as summer breeding ground, wintering ground, or as stopover points during migration (Crawford, et al 1993; Yong and Finch this issue). The Rio Grande bosque is extremely important habitat for numerous species of migrating songbirds. This habitat has been lost or fragmented through attrition due to alteration of the hydrologic regime through flood control, ground water pumping, and water diversions; agricultural development for grazing or cultivated croplands; or through development for commercial interests or housing. Thus, some species of songbirds have declined.

Three riparian species of songbirds which are known to breed or to have bred in the riparian forest of the middle Rio Grande are Bell's Vireo (*Vireo bellii*), Southwestern Willow Flycatcher (*Empidonax trallii extimus*) and Lucy's Warbler (*Vermivora luciae*). Another species known to breed in the middle Rio Grande valley is Scott's Oriole (*Icterus parisorum*) which is found in upland scrub habitats rather than riparian habitats. All four of these species are declining in numbers as a result of loss of habitat and/or parasitism by cowbirds. Only one of these four species, the SW Willow Flycatcher, is on the federal Endangered Species List at the moment. The other three species have recently been ranked by Partners In Flight/Aves De Las Americas as highly endangered, however, and unless something is done to protect them they may all become listed in the near future (Mehlman and Williams, 1995). Loss of riparian forest habitat is not the sole source of the problem for these species, of course. Deforestation of their winter grounds in Mexico, Central or South America is an additional problem. But available habitat on the breeding grounds in New Mexico is critical for reproductive success in many species (Yong and Finch, this issue). Lucy's Warbler for example, is a cavity nester and requires large diameter trees with old woodpecker holes for successful breeding whereas SW Willow Flycatcher requires dense willow scrub. Bell's Vireo has wider habitat preferences than the preceding species and may nest in mesquite. Scott's Oriole is found in upland scrub habitats in association with *Yucca* and *Agave* spp. If riparian forests and associated early successional stages were allowed to develop on state trust land they could meet the habitat requirements of a variety of bird species, over time (Warkentin, et al 1995).

Some sites on state trust land may have high potential for the development or restoration of riparian forests which could serve as essential links in the chain of such habitats along the length of the Rio Grande flyway for neotropical migrating songbirds. Historically, these riparian forests of the middle Rio Grande typically were composed of an overstory of cottonwood (*Populus fremontii*), and an understory and edge of willow (*Salix* spp.), New Mexico Olive (*Forestiera neo-mexicana*) and other shrubs. Today, the forests have been invaded by saltcedar (*Tamarix* spp.), Russian olive (*Elaeagnus angustifolia*), and siberian elm (*Ulmus pumila*). Whether these exotic invaders provide adequate habitat for native birds, insects, and small mammals is currently under investigation by a number of researchers (Thompson, et al 1994). Additional research is investigating whether native cottonwood riparian forests can be re-established and successfully compete with exotics given an altered hydrologic regime (Crawford et al, this issue).

Since the revenue stream from riparian forests on state trust land to the beneficiaries of the trust is generated entirely by livestock grazing and removal of all or a portion of the site from grazing via livestock exclusion will interrupt the revenue stream, it is not possible to not lease the land. As an alternative, it is possible to lease these sites to conservation groups who would be interested in riparian forest restoration. However, if the conservation group wishes to lease only a fraction of a larger lease, that is, only those sections with riparian habitat, the resulting loss of water for livestock may have negative consequences for the leasing of the remainder of the trust lands in the lease.

The following solution to this dilemma is a concept which is currently under consideration at

the state land office. First, lease those riparian areas with the highest potential for the development of forests to conservation groups which can fence the area, exclude grazing and allow a mature forest to develop over time. Second, develop a series of paddocks for a rotational grazing system in the transition zone between the riparian forest and the upland scrub vegetation where grazing cattle can be used as a management tool to control saltcedar, and maintain early successional riparian scrub habitat as proposed in Recommendation number 10, Middle Rio Grande Bosque Biological Management Plan (Crawford et al, 1993). These rotational grazing paddocks would be leased to both the conservation group and to the grazing lessee. The livestock producer pays the lease on the paddock in use and the conservation group pays the lease on the paddocks being rested from grazing. Four paddocks with one year of grazing followed by three years of rest may be a suitable proposal. The livestock producer pays the lease on the remainder of the upland scrub habitat and utilizes it for grazing livestock.

This concept offers several advantages. Of primary consideration is that the revenue to the beneficiaries is uninterrupted and unchanged. In addition, good stewardship of the riparian ecosystem and all of its components, including migratory songbirds, is initiated. And finally, cooperative management to attain a common goal may be obtained through facilitating a forum in which environmentalists and cattlemen can work together.

To date, this project remains a concept only. If a willing environmental group and a willing cattle grower can be found who are able to set their differences aside in order to protect the resources on which we all depend then this project can proceed. When it does proceed, and a site has been identified, then a research project at the site will be initiated. The initial research steps will be to gather baseline data on vegetation composition and structure, hydrology, soil types, and avian species composition and demographics. Determination of the location of the paddocks and the transition zone, the carrying capacity, the size of the paddocks and the placement of other sources of water for the cattle will depend on the result of this data collection. After that, fencing for exclosures and paddocks can proceed. Whether cattle can be used to control saltcedar at this site, or can serve as a management tool to enhance biodiversity through creating a variety of early successional habitat types, are questions which the study will seek to answer. Monitoring of the vegetation, birds, and hydrology will continue for the duration of the study.

REFERENCES

Crawford, C.S., A.C. Cully, R. Leutheuser, M.S. Sifuentes, L.H. White and J.P. Wilber. 1993. Middle Rio Grande Ecosystem: Bosque Biological Management Plan. Biological Interagency Team, U.S.Fish and Wildlife Service, P.O.Box 1306, Albuquerque, NM 87103.

Crawford, C.S., L.M. Ellis and M.C. Molles. 1996. The Potential for Implementing Partial Restoration of the Middle Rio Grande Ecosystem [this issue].

Mehlman, D.W. and S.O. Williams III. 1995. Priority Neotropical Migrants in New Mexico. NMOS Bulletin 23(1):3-8.

Thompson, B.C., D.A. Leal and R.A. Meyer. 1994. Bird Community Composition and Habitat Importance in the Rio Grande System of New Mexico with Emphasis on Neotropical Migrant Birds. New Mexico Cooperative Fish and Wildlife Research Unit, National Biological Survey, P.O.Box 30003, Dept. 4901, Las Cruces, NM 88003.

Warkentin, I.G., R. Greenberg and J.S.Ortiz. 1995. Managed Gallery Forest Patches as a Tool for Songbird Conservation in Southeastern Mexico *in* Programs and Abstracts, 9th Annual Meeting Society for Conservation Biology, 7-11 June.

Yong, W. and D.M. Finch. 1996. Use of the Middle Rio Grande Riparian Habitat as Migration Corridors by Neotropical and Short-Distance Migrants [this issue].

Public involvement and consensus building in the Verde River Watershed in central Arizona

Tom Bonomo[1]

Abstract.—Currently an organization called the Verde Watershed Association is the central point for consensus building and public involvement in water issues in the Verde River Watershed. The association is the out growth of efforts towards the resolution of watershed issues without passing new laws, initiating regulations, or entering the win-lose arena of litigation. The association is premised on the idea that truly effective river management and protection strategies cannot succeed without local consensus and support.

The establishment of the Verde Watershed Association and subsequent activities surrounding the association resulted in the national organization American Rivers removing the Verde River in Arizona from it's list of the 20 most endangered rivers in the Unites States.

At this time, this particular public involvement and consensus building structure serves as the primary focal point for the many activities going on in the Watershed, but as other efforts before have evolved into the present organization, this organization too may evolve into something more effective and participatory to achieve an even higher level of public involvement and consensus building.

INTRODUCTION

Two years ago American Rivers, the national free flowing river advocacy organization, took the Verde River in central Arizona off it's list of the 20 most threatened rivers in the United States. According to the American Rivers field representative for Arizona, the river was taken off the list because of the birth of an advocacy organization, the Verde Watershed Association.

The Verde Watershed Association is made up of representatives of towns, cities and county governments as well as representatives from commodity, recreation and environmental groups who believe that the solutions for the long term health of the Verde River are vested in consensus building, education, and informed decision making rather than regulation, legislation, or litigation. The Association has made a concerted effort to ensure that every major and minor stakeholder in the watershed is represented in the association and invited to join in the activities of the organization.

[1] *District Ranger, Prescott and Coconino National Forests, USDA Forest Service, located in Camp Verde, AZ 86322.*

PHYSICAL DESCRIPTION

It helps to understand the character of the water related issues of the Verde River Watershed if there is some awareness of the characteristics of the Verde River and it's watershed. The Verde River drains high country that is the Southwestern corner of the Colorado Plateau geologic area. The rivers headwaters are west of Williams AZ near Seligman and Ashfork AZ. The River becomes a flowing stream just below Sullivan lake in the eastern side of the Chino Valley. Not far below this point where the

river first flows to the surface it is joined by Granite Creek which is the outlet for the Prescott Basin. The river flows east for about 20 miles before it meets the next major drainage, Sycamore Canyon.

Sycamore Canyon drains the Coconino Plateau country between Williams and Flagstaff Arizona. Upon joining with Sycamore Canyon, the Verde River turns south-southeast and flows through the Verde Valley in central Arizona. Within the Verde Valley, the river is joined by three other major drainages that come off of the southwest corner of the Coconino Plateau.

These drainages are Oak Creek, Beaver Creek, and West Clear Creek. The southwestern corner of the Coconino Plateau begins what is called the Mogollon Rim along the east side of the Verde Valley and continuing east into New Mexico.

As the river leaves the Verde Valley it enters a narrowed area between the Mogollon Rim and the Black hills/Verde Rim along the east side of the Verde Valley. It is in this area that the Verde becomes the congressionally designated Verde Wild and Scenic River. As the river flows south, through the Verde Wild and Scenic River Area and the Matzatzal Wilderness in central Arizona, it is joined by two other major tributaries, Fossil Creek, whose waters provide water to the Childs and Irving hydroelectric power plants, and the East Verde River, which drains the Rim country between Payson, Arizona and the very distinct Mogollon Rim north of Payson.

Figure 2. Verde Cooperative River Basin Study.

The river flows south toward the Salt River Valley where it encounters Horseshoe Dam and Reservoir, the first of two major irrigation storage and flood control dams along the river. By this time the river has left the Matzatzal Wilderness and the Verde Wild and Scenic River Area about 10 miles behind. From Horseshoe Reservoir to Bartlett Dam and Reservoir on the river is about 7 miles. From Bartlett Dam and Reservoir, the river flows south for 15 miles through the Salt River Valley where it joins the Salt River a few miles east of Phoenix Arizona.

The Verde River watershed is about 6,600 square miles (4.4 Million acres) in total area. Sixty eight percent of the lands of the watershed are National Forest lands. The remainder of the lands within the watershed are primarily private and State land with small amounts of National Park Service and Native American reservation lands.

The Verde River was designated as a Wild and Scenic River in 1984 as a component of the Arizona Wilderness Bill for National Forest Lands. At this time it is the only designated Wild and Scenic River in Arizona. This river and it's tributaries and the associated riparian areas are habitat for 18 threatened or endangered species. The Verde River is one of the best examples left in Arizona of a large free flowing river in an desert environment.

WATERSHED ISSUES

The major threat to the Verde River is the potential for increasing groundwater pumping in the watershed to eventually dry up part or all of the river for parts of the year. The population within the watershed was 102,740 in the 1990 census, predicted to be 125,141 by the year 2000 and 234,400 by the year 2040 by Arizona Department of Water Resources in their statewide water planning documents[1]. There are

[1] *Arizona Department of Water Resources, Statewide Water Planning, 1994.*

an estimated 120,000 people in the Verde River Watershed at this time. A majority of these people live in either the Prescott area or in the Verde Valley. The population in the watershed grew by 58% in the 10 years between 1980 and 1990 and the growth is accelerating in the 1990's.

The real estate industry and construction industry in the Verde River Watershed is booming. One town in the watershed, Prescott Valley, grew over 30 percent during an 18 month period in 1993 and 1994. It has now slowed to a rate of growth of about 15 percent a year[2].

The flow in the Verde River for a majority of the year is from groundwater coming to the surface in springs or aquifers that feed the river. The flows at the lower end of the Verde Valley where the river becomes a designated Wild and Scenic River are between 50 and 200 cubic feet per second for 9 to 11 months each year. During periods of winter snow melt the river will flow to between 1000 and 6000 cfs for a period of 2 weeks to 2 months and during the summer rainy periods, the river will swell to the 300 to 500 cfs level for a week at a time.

Groundwater is the lifeblood of the Verde River. In addition to the communities and population within the watershed using groundwater there is valid reason to believe that communities located just outside of the watershed area may be using ground water that would become surface water flowing in the Verde River. The well fields that Flagstaff AZ uses to provide a significant amount of water to it's almost 70 thousand residents, are suspected to be tapping geologic formations that also provide spring water to Oak Creek, a major tributary to the Verde River[3]. The well fields used by Payson AZ are also suspected to be tapping aquifers that feed the Verde River System[4].

Over the last 20 years there have been numerous actions and events which have enhanced public involvement and awareness in Verde River and Verde Watershed issues. In the late 1970's Maricopa Audubon Society filed a lawsuit which forced the Forest Service to develop strategies and actions to protect Southern Bald Eagle and it's habitat. The Southern Bald Eagle had just recently been added to the Threatened and Endangered Species list. Most of the mitigation strategies centered around the enhancement of riparian habitat along the rivers and streams by improved livestock grazing practices.

One of then Governor Bruce Babbitt's last actions before he left office in the mid 1980's was to allocate money to Arizona State Parks for purchase of riparian lands for a Greenway along the river in the Verde Valley. Lands in the floodplain of the Verde River were purchased adjacent to Deadhorse Ranch State Park and have become the Verde River Greenway, a component of the Arizona State Park System. These land purchases were controversial in the beginning but the Greenway is now well supported by the public as they become more aware of the values of these lands.

In 1984 a 39 mile stretch of the Verde River below the Verde Valley was designated as Verde Wild and Scenic River as a component of the Arizona Wilderness Bill. Early public involvement in the Wild and Scenic River suitability study was heavy with public opposition to designation. When the designation of one segment of the river was included as a part of the Arizona Wilderness Bill 10 years later, opposition was light.

During the mid 1980's gravel mining in the Verde River floodplain was a common occurrence in the Verde valley. In 1986, concerns about the impacts of the alteration of the river channel caused by gravel mining in an area adjacent to the Verde River Greenway sparked action by State Attorney General. The Arizona Attorney General's office contended that under the equal footing doctrine, Arizona had never made it's rightful claim to the navigable waterways of the State and that the lands the gravel companies were mining were in fact state lands. The Equal Footing Doctrine is a policy supported in law whereby all states in these Unites States become states with the same rights and privileges that any other states had as they entered the Union.

This action sparked the Arizona State Legislature to pass a law that gave private landowners along the rivers of the state an opportunity to acquire a Quiet-Claim Deed to the floodplain lands adjacent to their property by paying a $25 per acre

[2] *Conversation with Ken Rittmer, Town Manager, Town of Prescott Valley, AZ, 1995.*

[3] *Conversation with Ed McGavock, Sedona AZ, retired administrator, US Geological Survey, 1994.*

[4] *Conversation with Dennis Sundie, Water Resources Planner, Arizona Department of Water Resources 1994.*

fee. This law has since been overturned by the Arizona Supreme Court and a second law was passed which charged the Arizona State Land Department to determine what watercourses were navigable at statehood and present these as the lands that should have become state lands upon statehood. Arizona State Land Department is still in the process of developing criteria to determine just what streamcourses were "navigable" at the time of statehood and thereby, which rivers and floodplains might actually be owned by the state under the Equal Footing Doctrine.

In the mid 1980's Threatened and Endangered Species habitat for a small fish called the Spikedace (*Meda Fulgida*) stopped proposals for removing water from the river to fill headwaters Central Arizona Project allocations. As part of the Central Arizona Project, 7 different entities in the Verde River Basin were given allocations for CAP water. It was assumed all along, that these communities, Cities and Tribes would take water that belonged to downstream water users in exchange for water flowing in the Verde River system. The downstream water users would trade this Verde water for CAP water from the Colorado River which would come to the Salt River Valley via the CAP canal.

The first city to actively pursue this option sought to place a withdrawal system in the upper Verde River to pump water to their city storage facilities. This proposal was dropped when it was determined that this withdrawal of water from the upper Verde River would have a negative impact on the habitat for the Spikedace.

PUBLIC INVOLVEMENT

In the late 1980's various individuals began a concerted process to develop public awareness and appreciation for the river and it's values. State and county elected officials and various agency heads became more aware of the Verde River's values after spending time floating on the river and appreciating the wildlife and lush vegetation along it. An annual event called Verde River Day was started in the Verde Valley as an appreciation day for the river. This event has been a huge success.

Many groups and organizations have formed over the last 10 years to discuss the water issues and other issues of the Verde River Basin. Some of these are rather formal and mandated by law such as the Prescott Active Management Area Groundwater Users Advisory Council, and some of these groups and organizations were more loosely associated like the Verde River Association, a group of agency staff, private citizens, Natural Resource Conservation Districts, Resource Conservation and Development Area representatives, and elected officials meeting periodically to discuss the Verde River issues in the Verde Valley.

One of these groups, the members of the Verde River Corridor project, met for over a year to discuss the issues along the Verde River in the Verde Valley. The Verde River Corridor Project was a locally directed effort with staff support from Arizona State Parks. There was representation on the steering group of all major and minor stakeholders along the river. The goal of the project was to examine all uses and values of the river corridor, agree on a common vision, and develop a plan of action that could be supported by the public.

The strength of process used in the Verde River Corridor Project was the acknowledgment of two simple yet essential ideas about river management. No public action can replace wise use of a river by those living along it. Effective river management cannot succeed without local consensus and support[5].

The Verde River Corridor Project was year long process that resulted in heightened awareness of the issues facing the river and pointed out the need for further actions. The process pointed out a need to address the water issues of the Verde Valley in a broader context by looking at the whole river basin, acknowledging the interconnection between all the water issues and addressing the total spectrum of these water issues.

To effectively address these issues, a member of the Yavapai County Board of Supervisors from the Verde Valley proposed that COCOPAI Resource Conservation and Development Area hold a conference to bring interested and affected groups and individuals in the watershed together. COCOPAI would facilitate discussion of water related issues in the basin and what the group

[5] *Verde River Corridor Project Overview, Tanna Thornburg, Arizona State Parks,1993.*

could do to begin understanding and addressing these issues.

COCOPAI sponsored the first Verde River Watershed Conference on April 20-22, 1992. On the first day of this conference 160 participants heard from about 15 speakers giving advice and information about the many and varied issues that relate to water in the Verde River basin.

The speakers urged communication, and seeking consensus in the resolution of the issues rather than litigation, regulation or legislation. The Conference participants agreed that solutions to issues in the Verde River Watershed would be better supported if generated by stakeholders through consensus building and they worked in small groups to develop ideas about a strategy or organization that could be used to facilitate this communication and consensus building.

The participants had many good ideas and agreed that a group of volunteers called a "bridging committee" should take the ideas and develop them into an organization that would best function to develop consensus and facilitate communication among the varied interests in the basin. The bridging committee met numerous times over the next 8 months and came to the consensus that an organization called the Verde Watershed Association should be formed.

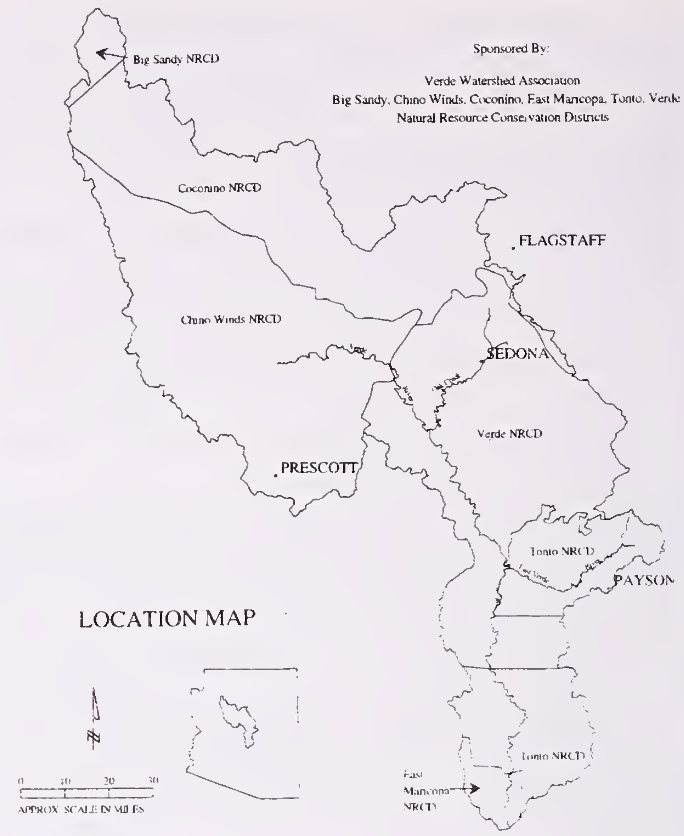


Figure 3. Verde Cooperative River Basin Study. Coconino, Gila, Maricopa, Mohave, Yavapai Counties, Arizona.

A proposed organizational structure was developed as well as proposed bylaws and organizational objectives. On January 16, 1993, the second Verde River Watershed Conference was held to formally organize the Verde Watershed Association.

The Association meets monthly at different locations in the Verde River watershed to educate and communicate about the issues, projects and new items of interest related to the watershed. The association also holds special meetings and seminars to address current issues and educate public about these issues.

State and Federal agencies are invited to participate and asked to provide assistance to the activities of the association, but are not members. This was a conscious decision by Association organizers to ensure that the local entities and individuals remain in the leadership roles within the Association and the activities and processes of the Association never become another state or federal problem solving activity with the baggage of, "we're from the government and we're here to help you".

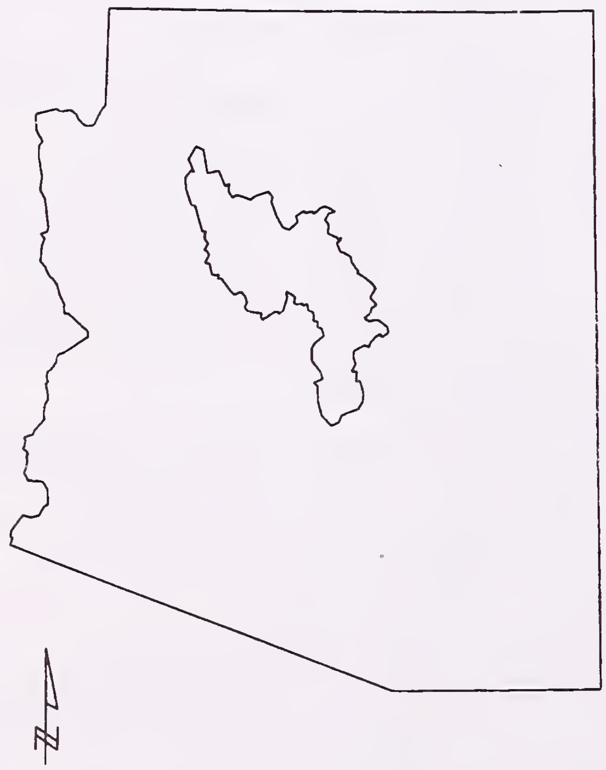


Figure 2. Verde Cooperative River Basin Study.

With the assistance of the Arizona Department of Water Resources, the VWA adopted a three phase plan for the development of a management strategy for the water resources of the watershed. Phase 1 is the gathering and compiling of existing information about water resources in watershed. Phase 2 will be to do further studies to fill in information gaps necessary to develop a management plan. Phase 3 will be the development of a water resources management strategy for the watershed with broad based public support.

VWA is currently applying most of it's effort in Phase 1, the information gathering and compiling phase although there are some efforts going on which fall into Phase 2 which will fill generally recognized information gaps by doing specific studies.

The Natural Resource Conservation Service (formally SCS) is currently conducting the Verde Cooperative River Basin Study in the Verde River watershed. This study is sponsored by the six Natural Resource Conservation Districts in the watershed with participation by all the agencies, both federal and state, that have an interest in the water issues in the watershed.

The goals of the Verde Cooperative River Basin Study are:

- Provide for continuous and widespread public involvement throughout the study period and beyond.
- Collect existing resource information from various sources (local, state, federal) and put it in a common, publicly available database.
- Determine what additional information is needed to allow for an accurate understanding of the basin's resources and associated issues[6] .

A comprehensive database compiled on a GIS (Geographic Information System) format will be used to allow local people to begin to plan for sustainable uses of the available water resources in the basin. The Verde Watershed Association has adopted a policy of encouraging all agencies doing studies to document in GIS format so data is more usable between agencies and by planners, decision makers, and the public.

A spinoff benefit of initiating Phase 1 of the Water Management Strategy for the Verde River Watershed has resulted in additional attention being given to the water resources of the watershed by state and federal agencies.

Arizona Department of Environmental Quality has established the Verde Management Zone for water quality planning.

The Verde Watershed Watch Network has been formed. This network is six watershed area schools nvolved in water sampling and testing as well as other activities related to water quality and riparian areas. The project is funded by grant monies from the Environmental Protection Agency and the project is administered by Arizona Department of Environmental Quality and Northern Arizona University.

The US Geological Survey is including the Verde River Watershed in one of the 60 National Water Quality Assessment Program projects in the nation. The Central Arizona Study Unit includes the Salt, San Pedro, Santa Cruz, Verde and a part of the Gila River. The Verde is included in the study because of the relatively pristine nature of the water and the strong biological component of the study. The National Water Quality Assessment Program is a long term program designed to study trends in the quality of a large percentage of the water used nationwide over a long period of time over different types of watershed areas by sampling for nutrients, pesticides, trace metals, and industrial organics.

The Environmental Protection Agency and the Army Corps of Engineers have determined which stretches of the Verde River are "potentially suitable" or "generally unsuitable" for the future discharge of dredged or fill material as part of the EPA Advanced Identification (ADID) process. This study identified the values inherent in the various reaches of the river and determined the probability for issuance of "404 permits" for dredge and fill activities in the reaches.

The Arizona Department of Water Resources has recently completed a project in the Verde Watershed investigating weather modification potentials. A significant component of the project was the development and testing of computer modeling of winter weather patterns moving across the central part of the watershed. It is hoped

[6] *Plan of Work, Verde Cooperative River Basin Study, Dino Desimone, Natural Resource Conservation Service, Arizona State Office, 1995.*

that this modeling will give better winter storm moisture prediction accuracy and better and earlier warning when storms with a potential for flooding are moving toward the watershed.

The Verde Watershed Association has been playing a role in these studies as a coordination point and by providing advisors to these studies.

Verde Watershed Association currently has a worldwide web site on the Internet and has a vision that this Internet connection will enable access by any agency or individual to the all of the existing information relating to the watershed. The Internet E-mail address is: *verde@sedona.net* and the Internet WWW Page address is: *http://www.verde.org/* .

The Internet activity of the Association as well as the publication of the Association newsletter, *The Confluence*, is funded by the Bureau of Reclamation through the Verde Natural Resource Conservation District. The Natural Resource Conservation Districts have provided a convenient legal mechanism for grassroots participants to enter into partnerships with federal and state agencies to do needed work. These partnerships can happen because of the many legal abilities that Natural Resource Conservation Districts have as subdivisions of the state. The Verde Watershed Association partnership with the Verde NRCD has proved to be a valuable asset in accomplishing work that otherwise could not be done.

It is unknown whether the Verde Watershed Association will grow into the 21st century as the appropriate structure to assist in the preservation of the Verde River as a flowing stream, but to date it has served it's purpose well and is currently the major catalyst for public awareness and information about the threats to the river.

PANEL

People and riparian ecosystems: Past, present, and future

Moderated by: Richard D. Periman[1] and Carol Raish[1]

INTRODUCTORY COMMENTS

By Richard Periman

The purpose of this panel is to review past, present, and future human needs and desires associated with riparian environments. Our focus concerns the diverse demands, interactions, and expectations that people have for the riverine lands. The discussion is designed to take place within historic, economic, and social/cultural contexts.

The use of historic context provides a perspective and framework within which the diverse and often controversial cultural, social, and economic values associated with riparian management may be addressed. The economic and social demands placed upon riparian areas often contrast sharply with the conditions needed to maintain the biological health of an area. Use associated with subsistence, recreation, or aesthetics, is often considered traditional, and therefore an integral component of traditional cultural values. This vast assortment of human demands presents a complex challenge for land management planning, future development, and the maintenance of traditional uses.

Frank Wozniak, Historian and Consultant to the Forest Service, Southwestern Regional Office in Albuquerque, provides an overview of the historic development of the area: setting the stage for the discussion. David Brookshire, Chair and Professor of Economics at the University of New Mexico, addresses current and future economic issues and demands relating to development and riparian ecosystems. Tony Barron, with the Parks and General Services Department, Open Spaces Division of the City of Albuquerque, examines issues and demands relating to recreational uses and opportunities along the Rio Grande.

HISTORY AND USE BY ETHNIC GROUPS

By Frank E. Wozniak[3]

I have suggested elsewhere in this volume that Spanish missionaries and government officials imposed an irreversible reliance on irrigation agriculture upon the Pueblo Indians during the 17th century. This socio-economic change irretrievably undermined and altered traditional Puebloan land use patterns and lifeways. When the opportunity came during the Pueblo Revolt (1680-1693) to reject this subsistence system, its accompanying technology and introduced plants and domesticated animals, the Pueblo Indians ignored the directions and wishes of their religious leaders and continued to utilize Spanish plants, animals and technologies, and to engage in intensive irrigation agriculture. The Pueblo Indians survived in the 18th, 19th and 20th centuries, essentially as subsistence farmers who relied on irrigation agriculture and livestock raising.

After the Pueblo Revolt, the Spanish settlement system in New Mexico was transformed. The Spanish government made grants of land to self-sufficient Hispanic communities in order to ensure the effective occupation and defense of New Mexico. These land grant communities supported themselves by their own labor through irrigation agriculture and livestock raising.

---

[1] *Research Social Scientists, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Cultural Heritage Research Work Unit, located in Albuquerque, NM.*

[3] *Historian and Consultant to the Forest Service, Southwestern Regional Office in Albuquerque.*

When the Anglo-Americans occupied New Mexico in 1846, they found a largely self-sufficient agrarian society that was concentrated in the riparian zones of the Rio Grande Valley. With the arrival of the railroads in the 1880s, came the end of the economic stability that New Mexican farmers had known for nearly two centuries. This circumstance was brought about by the introduction of the commercial economy of the United States into New Mexico. I will not comment here on the exploitation of the natural resources of the West in the 19th and 20th centuries as we are all familiar with these developments and their impacts on riparian and other ecosystems. Though more urbanized and subject to outside influences than other parts of New Mexico, the residents of the Middle Rio Grande Valley maintained traditional patterns of land use until the 1920s. Up to the 1920s, at least 90% of Middle Rio Grande Valley farmers were Hispanic or Pueblo Indian and approximately 90% of irrigated acreage was farmed by Hispanics and Pueblo Indians.

The breakdown of traditional land use patterns in the Middle Rio Grande Valley during the 1920s and 1930s was due to economic depressions and to changes in the patterns of relationships with irrigation agriculture on the part of the farmers themselves. The changes in relationships with irrigation agriculture were associated with the organization of the Middle Rio Grande Conservancy District (MRGCD) in 1925. The MRGCD emerged as the solution to Middle Rio Grande Valley problems related to water shortages, sedimentation, aggrading of the main channel of the Rio Grande, waterlogging, seepage and salinization of soils. Especially important in the impacts on farmers was the break in the link between the irrigation of the land and ditch maintenance. After the late 1920s, the MRGCD assumed the maintenance of the ditches from the water users who paid a fee for this service. The whole process was voluntary and with the consent of the irrigators. The new system replaced the previous system of community ditch maintenance and thus broke the individual farmers connection with community agricultural endeavors.

In historic times, riparian resources in the Middle Rio Grande Valley were utilized by three groups: American Indian, Hispanic and Anglo-American. Some studies of cultural values regarding land and water uses do exist, but these studies tend to be simplistic. It is generally assumed that American Indians, Hispanics and Anglo-Americans have different world views and therefore, different cultural values regarding land and water resources. There has never been sufficiently detailed study to determine if there really are substantially different cultural views of land and water use among American Indians, Hispanics and Anglo-Americans in the Rio Grande Valley. Discussions on the allegedly different cultural views have been fueled by simplistic and romantic views within our present industrial society about subsistence farmers and their relationships with the land. American Indian and Hispanic cultural values in New Mexico are seen as tied to their earlier roles as subsistence farmers. The question that must necessarily be addressed is: Are the cultural values regarding land and water different among Pueblo Indians, Hispanics and Anglo-Americans? If so, how do they differ and do those presumptively different values play a significant role in how these three groups utilize land and water resources? Studies of cultural values that do not romanticize certain groups and demonize others are a fundamental foundation for any understanding of the relationship between humans and riparian ecosystems.

ENDANGERED SPECIES IN RIPARIAN SYSTEMS OF THE AMERICAN WEST

By David S. Brookshire[4], Michael McKee, Christian Schmidt

INTRODUCTION

This paper examines the economic impact of critical habitat designation for three fish species endemic to the Virgin River: the woundfin, Virgin River chub, and Virgin spinedace.[5] The woundfin and the Virgin River chub are listed as Endangered; the Virgin spinedace is proposed for listing as Threatened (the three fish are referred to collectively as the "listed fishes").

---

[4] *Department of Economics, University of New Mexico, Albuquerque, NM 87131-1101.*

[5] *For a detailed discussion of the economic effects of critical habitat designation, please refer to Brookshire et al.*

The Virgin River crosses southwestern Utah, the northwestern corner of Arizona, and part of the southern tip of Nevada before flowing into an arm of Lake Mead. Preserving and restoring the listed fish species would require that Virgin River water for future uses be used for industrial, domestic, and agricultural purposes in conjunction with flows for the listed fishes.

The two counties that would be directly affected by actions taken on behalf of the listed fish are Washington County, Utah, and Clark County, Nevada. These are among the fastest-growing areas in the United States: Washington County's population grew by 52% in the period 1980-1990, while Clark County's grew by 62.5% in the same period. Continued growth is expected in these counties. The Virgin River also flows through a portion of Mohave County, Arizona, but this area has a very small population and modest economic activity. Iron County, Utah, another rapidly-growing area, lies to the north of Washington County and is closely linked with it economically. Although the Virgin River does not flow through Iron County, any economic impacts on Washington County would be felt in Iron County as well. The region covered in this study is shown in Figure 1. The region's economy resembles in many ways that of the Rio Grande Basin. The arid climate and rapid urbanization are similar to the Rio Grande Basin as well.

Figure 1. Generalized location of the Virgin River basin.

METHODOLOGY

This analysis uses the input-output method of economic modeling to investigate the impacts of listing and critical habitat designation for the Virgin River fishes. Input-output models are a way of describing an economy by representing it as a series of "linkages" between the various production sectors. Once a model has been constructed for a particular economy, it can be used to investigate "what if" scenarios, such as the impact of exogenous shocks on that economy. A shock will have direct impacts: for example, production of a particular commodity will be curtailed because a basic input (such as water) has become scarce. Because of the linkages in the economy, a shock will also have indirect impacts: for example, lower production will affect employment and income in that sector, while the higher cost of a scarce commodity means that less disposable income can be spent on the products of other sectors of the economy. Ultimately, the shock is reflected in a change in final demand for products of the regional economy.

Input-output models are well suited to characterize the impacts of an exogenous shock on a small regional economy such as that of the Virgin River basin. The IMPLAN data sets, which permit construction of county- and regional-level models, were used as a basis for this study. These were augmented by local population growth projections produced by the Las Vegas Valley Water District (LVVWD, Clark County) and the Washington County Water Conservancy District (WCWCD, Washington and Iron counties).

The method followed in this study was to construct a baseline projection for the regional economy as a whole, plus separate baseline projections for Clark and Washington counties. Two alternative scenarios were then developed to reflect actions taken to protect the listed fish species: one scenario compares the projected effects of these actions against the baseline, while the second shows the effects compared to the baseline if water conservation policies are implemented in the affected region.

All three scenarios investigated in this study are based upon the assumption that population growth rates in the region will be sustained throughout the study period, although some decline is expected as desirable building areas become scarce. The water needs of the growing population will be met by constructing a series of structural projects to increase the region's supply of water for municipal and industrial uses, as well as to improve water quality in the Virgin River. In addition, retirement of agricultural land is anticipated as water and agricultural land are allocated for other uses.

SCENARIOS

The **"without fish" baseline (WOFBA)** was projected for the region as a whole, as well as for Washington County and for Clark County. This scenario is based upon the plans of the two regional water districts for meeting the area's water needs through structural projects and agricultural retirements. The **"with fish" structural (WFST)** scenario uses the same assumptions, but the region's available water supply is shared by the amount necessary to provide instream flows to protect habitat for the listed fish species. In both scenarios, per-capita water consumption is projected to remain the same as at present. The **"with fish" conservation (WFCO)** scenario begins with the same assumptions as the WFST scenario, but per-capita water consumption is reduced by implementing water conservation measures. These include installation of water-saving devices (appliances, plumbing, etc.) and use of xeriscape landscaping in new construction.

The WFST scenario has three direct impacts: earlier retirement of agricultural land as the water is diverted to other uses, hence a decline in agricultural production; increased cost of water because structural projects must be built earlier, reducing the amount of income that can be spent elsewhere; and loss of revenue to the WCWCD because diverting water to the river to preserve fish habitat will cause a decline in the production of two small hydroelectric power facilities operated by the water district. The WFCO scenario adds the cost of water conservation expenditures (e.g., for low-flow toilets and timed sprinklers). These costs will chiefly impact the construction sector of the economy, but the water delivery projects are able to be delayed with the result that costs are reduced.

RESULTS

Under the WFST scenario, the present value of output changes in the Washington County economy due to fish considerations is -$47.5 million, which constitutes 0.0016% of the present value of the baseline stream of output (WOFBA). The annualized value equivalent is -$1.95 million. Employment and earnings effects are presented in the report, and are of a magnitude similar to that of the output effects.

For Clark County, the output effects of the fish considerations are -$10.63 million. The baseline economy of Clark County is much larger than that of Washington County, so the relative effects of the designation of critical habitat are correspondingly much smaller. Thus the **cumulative output effects represent only 0.00001%** of the baseline level of economic activity. Both the earnings and tax revenue effects are too small to be reliably reported as deviations from the baseline level of economic activity.

For the region as a whole, the output effect of designating critical habitat is -$59.8 million (0.0001%). The other aggregate effects are of similar relative magnitudes.

Water use conservation is able to significantly mitigate the effects of listing and designating critical habitat. This is also true for the critical habitat effects alone. Under the WFCO scenario, the present value of the output changes in Washington County is -$13.7 million, 0.00046% of the baseline level of activity. For the region as a whole, the output effects of designating critical habitat are -$20.9 million, an amount too small to calculate as a percentage of the baseline. There are no conservation scenario impacts for Clark County.

CONCLUSIONS

The impact of critical habitat designation for the three listed fishes is very small when viewed in the context of the regional economy. Meeting increased water needs on behalf of the fishes will only accelerate the current trend of converting agricultural water uses to municipal and industrial uses.

CITATIONS

Brookshire, D.S., M. McKee, and C. Schmidt, August 1995. *Economic Analysis of Critical Habitat Designation in the Virgin River Basin for the Woundfin, Virgin River Chub, and the Virgin Spinedace.* Prepared for U.S. Department of the Interior, Fish and Wildlife Service, Salt Lake City, Utah. 232 pp.

CURRENT AND FUTURE RECREATIONAL ISSUES

By Tony Barron[6]

The management of riparian areas creates a unique challenge for the riparian resource manager. Due to many adverse historical use patterns, managers must utilize aggressive low impact management techniques. Some of these techniques are compatible recreational uses, fire management programs, restoration of burned or deteriorated areas, volunteer programs, educational and interpretive programs and a presence of law enforcement.

When various projects must be facilitated, buffer areas should be established and maintained along with vehicle access controls which will provide protection from urban encroachment. Limited recreational use can be provided in the riparian area, and sound management practices must be utilized to minimize the destruction of vegetation and creation of unwanted trails. We should whereever practical and feasible provide ADA handicap accessibility. Trails should be marked and signage should be provided.

Opportunities within the bosque provide a wide range of opportunities and recreational experiences. Various official access points must be established and these areas should provide information for hiking, jogging, nature walks, ADA accessibility, areas that are closed, and rules, regulations and ordinances. These management objectives when implemented will reduce drainage for these riparian areas. Many times this and other damage can be reduced because a tremendous amount of damage can be caused by too many accessing or concregating in one location.

Expansion and diversification should be one of the major concerns of the riparian resource manager. Improved access and designation of official access points will provide increased recreational and educational opportunities.

The interfacing of volunteer programs such as "Trail Watch Volunteers" along with a strong law enforcement educational presence will enhance the experience of the user of these riparian areas.

Safety is a major issue for both managers and users of the bosque. Sensitive areas having cultural and historical values should be protected. The safety of our visitors to these areas will be one of the major priorities of the riparian resource manager. Passive recreation is recommended and will limit liability using education, access, and controls. Directing and encouraging park users to stay away from hazardous areas or situations and encouraging responsible use of our loved and valued riparian area is critical.

On-going monitoring programs must be established to insure effective management goals, objectives, and practices. Bold management decisions must be implemented whenever data from on-going monitoring efforts dictates the need for appropriate review up to and including the possibility of changes in current management practices.

CONCLUDING COMMENTS

By Carol Raish

As the panelists have emphasized, the future of the Rio Grande riparian ecosystem is affected by both present-day and historical factors. In order to be successful, future land management planning and development must take these factors into consideration. In his historical review of the valley, Frank Wozniak makes the important point that three different ethnic groups; the American Indian, the Hispanic-American, and the Anglo-American; reside in and use the riparian area. Differing cultural values concerning land and water use, stemming from presumed differences in world view, are often attributed to these groups. Wozniak calls for detailed, non-romanticized

[6] *Operations Manager, Open Space Division, City of Albuquerque, NM.*

studies that explore the basic questions of whether or not culturally conditioned differences in values concerning land and water use actually do exist among these groups. And if so, do these differences play a role in the way in which land and water resources are utilized? Answering these questions is crucial if land managers are to work effectively with local groups to manage the resources of the area now and in the future.

Wozniak also reviews the historical subsistence system of small-scale, irrigation agriculture and stock raising, which favored by the Indian and Hispano groups, was introduced by the Spanish in the late 1500s and persisted until the 1930s. Major economic changes began in the 1880s, when the railroad brought the area into the sphere of the commercial U.S. economy. These changes escalated in the 1920s and 1930s with growing population and development of the Middle Rio Grande Conservancy District (MRGCD). The MRGCD was designed to combat land and water problems caused or exacerbated by commercial stock raising, farming, and logging that flourished under Anglo-American control of the valley, especially after 1880. Ultimately, operation of the system led to a breakdown in the traditional land use patterns of the small farmers and a growing commercialization of the valley.

Growing populations, with attendant commercialization and industrialization in riparian areas, are common not only in the Rio Grande but also in many other riparian zones of the arid West. This growing industrialization, with declines in small-scale, mixed farming and retirement of agricultural land, is addressed by David Brookshire. Both traditional agricultural lifeways and threatened or endangered species, such as the fish species discussed here, are affected by these changes in economic orientation. Brookshire uses an input-output model to examine the economic impacts of various different treatments of the fish species. In this way, he is able to quantify the effects of fish protection/non-protection on the local and regional economies. The study concludes that the impacts of the protection strategies are actually very small when examined in the context of the regional economy and that providing for the fish can be accomodated within the framework of current trends in conversion of water from agricultural to municipal and industrial uses. Studies such as this one provide valuable analytic tools for assessing the economic effects of the many competing riparian area desired future conditions faced by land managers, developers, and municipalities.

Finally, along with the shift in economic emphasis from the small, family farm of a century ago to greater commercialization and urbanization, there is a growing concern for conservation and protection of both endangered species and habitat. There is also a growing desire to use riparian areas for recreational, educational, and aesthetic purposes. Tony Barron examines this potential conflict in his discussion of managing riparian zones in an urban context. He stresses the importance of managing these areas so that they are protected from urban encroachment and destruction of fragile resources, while at the same time providing for the recreational needs of an expanding urban public.

Today's panel has reviewed and discussed the difficulties and challenges facing riparian area managers now and in the coming years. Those charged with designing the future of these fragile areas must develop strategies to balance the goals of maintaining traditional lifeways, protecting endangered species and habitat, and providing recreational and educational experiences within the context of an expanding urban population center.

Ecosystem restoration and species recovery

Albuquerque constructed wetlands pilot project: Summary and status of City of Albuquerque project, September 1995

Steven Glass[1], Joan Thullen[2], Jim Sartoris[2], and Rick Roline[3]

INTRODUCTION

The Pueblo of Isleta, located five miles downstream from Albuquerque, and the NM Water Quality Control Commission has established strict water quality standards for the Rio Grande, and it has become necessary for the Albuquerque Public Works Department to pursue methods to enhance the purity of treated municipal wastewater effluent produced at the Southside Water Reclamation Plant (SWRP). In response to requirements in a National Pollutant Discharge Elimination System (NPDES) permit, issued in June 1994 by the US Environmental Protection Agency (USEPA), design has begun for additional facilities at SWRP to support biochemical processes that effectively reduce nitrogen during wastewater treatment. However, the NPDES permit, in recognition of State and Pueblo stream standards for the Rio Grande, contains potential discharge limitations for several substances other than nitrogen, including arsenic, silver, aluminum and cyanide. In addition, the permit requires that an interagency evaluation of existing Rio Grande water quality be completed within three years, to provide a foundation for future decisions about the river.

THE CONSTRUCTED WETLANDS STUDY GROUP

The Albuquerque City Council and the Bernalillo County Commission, recognizing the need to explore alternative methods for treating municipal wastewater to higher levels of purity, commissioned the City/County Constructed Wetlands Study Group, in October 1992 and in August 1993, respectively. Goals of the Study Group were to evaluate the status of natural wetlands in the Albuquerque reach of the Rio Grande; to ascertain the impact of new discharge limits on City wastewater treatment operations, including a scoping study of future compliance options and costs; and to examine the applicability and impacts of constructed wetlands for wastewater treatment in Bernalillo County.

In their December, 1993 Final Report to the City Council and County Commission, the Constructed Wetlands Study Group concluded that constructed wetlands represent a proven technology for wastewater treatment that offer added benefits related to wildlife habitat and aesthetic enhancements. Constructed wetlands have been successful in small to medium scale applications for domestic sewage, municipal wastewater, urban stormwater runoff, industrial effluents and mine seepage. However, the Study Group found insufficient available data to establish the efficacy of constructed wetlands for tertiary treatment of large volumes of treated effluent from a municipal wastewater facility. Moreover, no unified system exists for regulating, certifying, operating or monitoring constructed wetlands treating wastewater, which often poses a public health risk. Finally, the Study Group expressed some concern about the effects of evapotranspirative water loss from constructed wetlands on City water rights, and suggested that aquifer recharge feasibility be examined if wastewater effluent could be adequately purified.

The December 1993 final report by the Constructed Wetlands Study Group report contained two major recommendations for further action:

[1] *City of Albuquerque, Public Works Department, Wastewater Utility Division, Albuquerque, NM.*

[2] *National Biological Service, Denver, CO.*

[3] *US Bureau of Reclamation, Denver Technical Center, Denver, CO.*

- Establish and operate a constructed wetlands pilot facility to rigorously evaluate tertiary treatment efficacy for municipal wastewater effluent, and
- Pursue the lease or purchase of properties down-gradient from the SWRP that can be used for full scale constructed wetlands, if the technology proves appropriate for polishing large volumes of treated municipal effluent.

THE CONSTRUCTED WETLANDS PILOT PROJECT PLANNING COMMITTEE

In early 1994, City Councilor Vickie Perea led the City Council in adopting resolutions that appropriated funds to pursue the Study Group recommendations. From the contingency allocation of a multimillion dollar contract to construct nitrogen removal facilities at the Southside Water Reclamation Plant, the Council diverted $10M for the purchase of property that can be converted into constructed wetlands in the future. Negotiations have been initiated toward the purchase of a privately-owned 500-acre parcel south of the treatment plant. It is envisioned that the property, if not converted to a large-scale constructed wetlands for effluent polishing, will be transferred to the City of Albuquerque Open Space Division to provide streamside habitat and recreational potential for the public.

Also based on the Study Group recommendations, the City Council appropriated $500,000 in March 1994 to support the construction of a pilot wetlands facility at SWRP. Discussions about the Study Group recommendation for a pilot constructed wetlands facility led to consideration of two options. A thirteen-acre parcel of land within Southside Plant boundary could be utilized for a constructed wetlands demonstration area. Alternatively, numerous obsolete concrete sludge drying beds were available for potential conversion to constructed wetlands test cells.

A 1994 joint agreement between the Directors of Planning and Public Works Departments, approved by the Chief Administrative Officer, established the Constructed Wetlands Pilot Project Planning Committee (CWPPPC), representing City, County and public interests. CWPPPC membership initially included representatives of the Albuquerque Public Works Department, Wastewater Utility Division; the Albuquerque Planning Department; the University of New Mexico, Department of Architecture and Planning; the Albuquerque Parks and General Services Department, Open Space Division; the Albuquerque Department of Finance and Management, Real Property Division; the Bernalillo County Environmental Gross Receipts Tax Advisory Board; and the Bernalillo County Environmental Health Department.

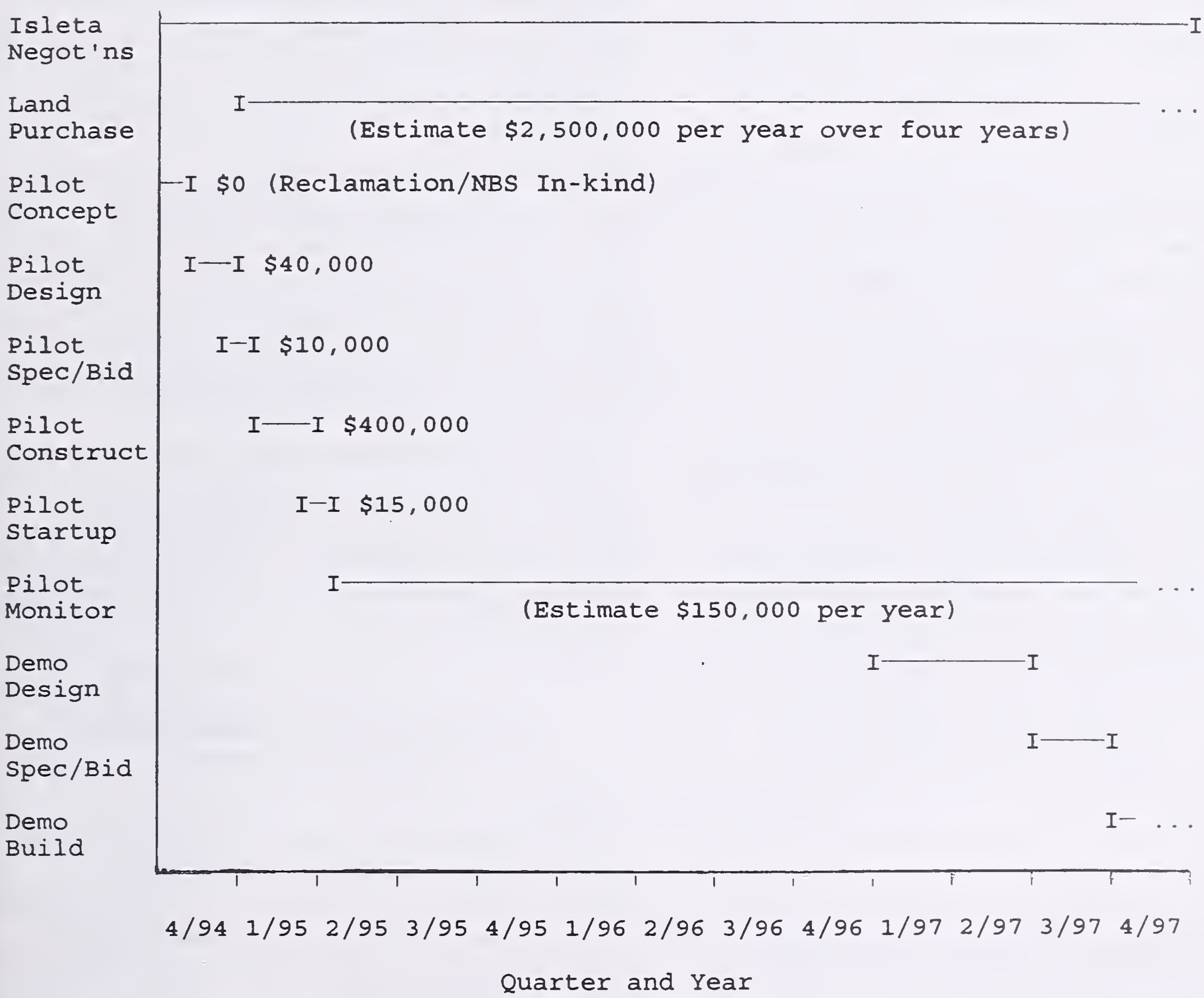
In the early stages of CWPPPC work, efforts were made to encourage financial support for the pilot project from Bernalillo County. Appendix A includes handouts prepared by the Committee for a presentation to the Bernalillo County Environmental Gross Receipts Tax Advisory Board. As CWPPPC efforts progressed, however, personnel changes within the County administration resulted in withdrawal of County representatives from the Committee.

Ultimately, the Committee recommended construction of a small-scale pilot wetlands facility to be operated for three years. Design and operations parameters developed from the pilot study could be used for subsequent installation of a demonstration-scale constructed wetlands on a 13-acre parcel of property available at the Southside Water Reclamation Plant. However, certain stipulations in the Albuquerque National Pollutant Discharge Elimination System (NPDES) permit could preclude the demonstration-scale study.

CONSTRUCTED WETLANDS PILOT FACILITY DESIGN PROPOSAL

The CWPPPC was made aware of a technology development support program operated by the US Bureau of Reclamation, and contacted the local Reclamation office. With the assistance of the NM Environment Department Surface Water Quality Bureau, a request for assistance was submitted to Reclamation. As a result, wetlands experts with the National Biological Service (NBS) and the Reclamation Denver Technical Center provided in-kind conceptual design support for the pilot wetlands facility at SWRP, and presented a proposal to the CWPPPC in November 1994. The

City of Albuquerque
Constructed Wetlands for Wastewater Treatment
Proposed Pilot and Demonstration Scale Projects Timeline



designers opted for conversion of the obsolete sludge drying beds at the Southside Water Reclamation Plant into constructed wetlands test cells, but left open the possibility of building a future demonstration wetlands facility on a thirteen-acre parcel south of SWRP. Although the original proposal envisioned the conversion of 21 obsolete sludge drying beds at SWRP into wetlands test cells, time and financial constraints reduced the scale of the final proposed facility by half to 10 test cells, treating only effluent from the Southside Water Reclamation Plant. City Appendix B includes excerpts from the final proposal.

Based on the final conceptual design by the NBS and Reclamation, the following proposed project timeline was developed in November 1994 by the Constructed Wetlands Pilot Project Planning Committee.

Council-sponsored review of the final proposal by local wetlands consultant Ross Coleman of Hydra raised concerns about the balance in the project design between general wetlands research and the specific effluent quality improvement objectives facing the City. Concerns were also expressed by CWPPPC representatives about the apparent lack of emphasis in the final proposal on wetlands use in smaller scale residential applications or wetlands use for urban runoff remediation. Committee members recommended that an effort be made to coordinate the proposed SWRP pilot project with separate ongoing and planned projects, targeted at evaluating constructed wetlands performance for treating residential wastewater and urban runoff. Specific companion programs include the constructed wetlands assessment and demonstration program funded by the Bernalillo County Environmental Gross Receipts Tax; and a constructed wetlands installation at the outfall of an urban stormwater discharge, planned by the Albuquerque Public Works Department Hydrology Division for their Osage la Media project.

PILOT FACILITY DESIGN CHARETTE

In light of unresolved differences of opinion within the CWPPPC about the most appropriate design for a constructed wetlands pilot project at SWRP, it was determined that independent experts in the field should be assembled for an intensive peer review session, or "charette." Accordingly, representatives of the Albuquerque City Council, City staff, Bernalillo County staff and interested citizens met January 21, 1995 at SWRP with constructed wetlands experts to conduct an intensive peer review of the proposed pilot wetlands facility, using the NBS/Reclamation proposal as a framework for discussion. Two trained facilitators, Rick Mack with the City and Ric Richardson with UNM, were retained by the City to assist charette participants in focusing discussions for maximum effectiveness. Ultimately, charette participants arrived at a consensus for pilot facility design that includes six duplicated constructed wetlands configurations, in which both monoculture and polyculture plant communities are represented. Research objectives were focused on examining heavy metals removal efficiency, nitrogen kinetics and moisture loss rates through evapotranspiration. A summary document, based on facilitators' notes, is attached as Appendix C. The following diagram provides a simplified illustration of the twelve test cell configurations established during charette discussions.

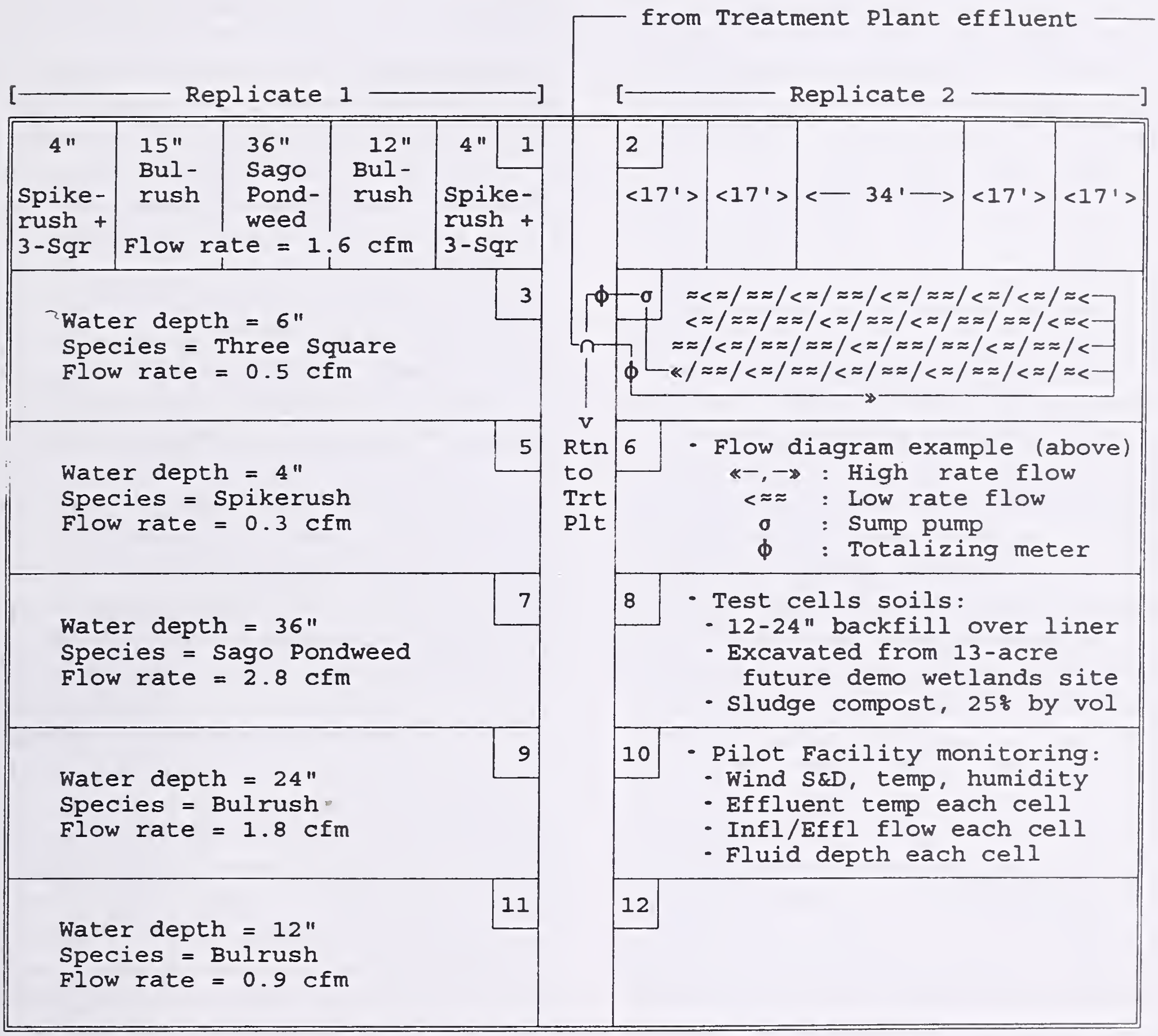
Appendix D includes written opinions about the proposed City program, offered by members of the public and by experts in constructed wetlands technology. Of the experts who provided written opinions, only Sherwood Reed participated in the January 1995 charette.

PILOT FACILITY DESIGN AND CONSTRUCTION

Immediately following the charette, final pilot facility design services were secured from Molzen-Corbin and Associates via a change order to an existing contract with the Albuquerque Public Works Department. Drawings were completed and approved for construction in late March 1995.

Two construction companies, each with existing contracts at the Southside Water Reclamation Plant, were provided final facility drawings and asked to provide quotes for pilot facility construction if completed under change order. After opening sealed quotes April 19, the Wastewater Division Facilities Engineering Section awarded the

City of Albuquerque
Constructed Wetlands Pilot Facility
Schematic Diagram



Note (06/30/95): Flow rates subject to confirmation by CWPPPC. Flow rates shown assume 72 hour detention time in each cell.

construction work to RMCI. Excavation of twelve former sludge drying beds at the west edge of the SWRP property began April 20, 1995.

In mid-June 1995, RMCI finished excavating the twelve former sludge drying beds. Ground water was encountered at a depth of 4.5 feet below grade, forcing some redesign of the four test cells for which deep water trials are planned. Consultation between the City, RMCI, Ross Coleman (Hydra) and Joan Thullen (National Biological Service) established that maximum water depths in the deeper cells could be limited to 36 inches, accomplished by reducing soil backfill from 24 inches to 12 inches depth. Both Coleman and Thullen are confident that the reduced depth will not materially affect the value of the constructed wetlands trials.

Excavated test cells were lined with polypropylene, and plumbing to deliver SWRP effluent to the test cells was installed. Soil, augmented with compost produced at the City biosolids composting facility, was used to fill lined cells in preparation for planting procedures. Compost augmentation is intended to simulate accumulated decaying plant detritus in the soil, allowing more rapid attainment of a mature, equilibrium state for ecosystems represented in the test cells.

The original change order to RMCI, under which the wetlands pilot facility was constructed, included an allocation for purchase of wetlands plants in numbers and of species defined by the Constructed Wetlands Pilot Project Planning Committee, in consultation with the National Biological Service. RMCI selected local supplier Hydra to provide the necessary plant materials. Under the planting subcontract with RMCI, Hydra was required to obtain a performance bond for the vitality of plant materials provided for constructed wetlands use. To ensure the survival of plants in the wetlands test cells, it was deemed vital that installation of the plants be accomplished by a few small teams of 4-6 competent individuals following strict planting procedures.

Responding to the emphasis placed on public information and participation during the Wetlands Pilot Project Charette in January 1995, both the City and Hydra thoroughly explored alternatives that would allow public assistance in planting the test cells. While members of the general public are unlikely to possess the necessary horticultural skills, the Albuquerque Area Master Gardeners' Association were considered likely candidates for planting volunteers. However, after consulting with the Master Gardeners' coordinator at the Bernalillo County Cooperative Extension Service office, it was determined that the degree of exposure and rigor of the planting work is excessive for most Master Gardeners, who tend to be elderly retired citizens. It was ultimately decided that Hydra should assume primary responsibility for installing plants in the constructed wetlands test cells, with assistance as needed from staff from RMCI, the City and the National Biological Service. Test cells planting was completed between June 19 and June 22, except that the deepest cells (7 and 8) were not planted because Sago Pondweed tubers were not available.

Sago Pondweed, specified during the Charette for the deep test cells and for the polyculture test cells was found to be unavailable from suppliers in the United States at the time of pilot facility planting. Sago Pondweed must be shipped in the tuber form, which cannot be harvested after the plants germinate, and the June planting schedule for the Albuquerque pilot facility postdated the annual germination period for pondweed. The NBS recommended an *Elodea* species as a substitute species, and Hydra initially concurred. However, after further consideration it was mutually determined that Elodea requires a cooler climate and clearer water, and would not thrive in secondary effluent. A decision was therefore reached to postpone planting Sago Pondweed in the deeper pilot facility test cells until April 1996. The deep cells (7 and 8) will be operated essentially as typical wastewater oxidation ponds, and the effects of volunteer algae growth will provide useful data for comparison with subsequent information gathered after pondweed is planted. In multiple depth cells, the planned polyculture plant community will be minimally affected by the temporary delay in the pondweed planting schedule.

Wastewater Division instrumentation technicians, with financial assistance from the National Biological Service, acquired equipment and hardware necessary for monitoring test cell effluent temperatures, solar energy, wind speed and direction, air temperature, humidity and precipitation at the pilot facility. Numerous opportunities to redeploy idle instrumentation from other Waste-

water Division applications have been exploited to reduce costs, and the NBS is funding the purchase of most new equipment needed.

DESIGN, CONSTRUCTION AND OPERATIONS COST ESTIMATES

Original facility construction estimates were provided by Reclamation in their project proposal. Costs to convert 10 obsolete sludge drying beds into wetlands test cells were estimated at $400,000, or $40,000 per cell. During charette discussions, a decision was made to substitute less expensive 40-mil polypropylene liners for the Hypalon liners specified in the proposal. From discussions with a local liner supplier, savings were estimated at $14,000 for twelve test cells, or $1167 per cell, bringing the construction costs estimate to $38,833 per cell.

No funds were allocated to final design costs in the original proposal. The design consultant quoted a cost of $40,000, increasing facility implementation costs to $42,166 per test cell.

Costs for acquiring and installing wetlands plants in the test cells were included in the NBS proposal, and were estimated at $13,100 for 10 test cells. The actual bid from Hydra under its subcontract with RMCI for plant materials to install twelve test cells is $22,820, which increased to $42,000 when RMCI markup and support labor were included. Some potential savings in planting costs were proposed during charette discussions, such as harvesting plants from local ditch-banks and using volunteer labor to plant the test cells. For purposes of these estimates, however, a cost of $3500 per cell was assumed for planting. Including planting, pilot facility implementation costs are estimated at $45,666 per test cell, or $547,992 for the entire 12-cell pilot facility.

It is estimated that operational support for the pilot facility will entail two visits per shift, two shifts per day, seven days per week by an Wastewater Operator II, for purposes of data collection, flow adjustments, minor maintenance and sample collection. A duration of one and one-half hour per visit seems adequate, with occasional longer times for more significant equipment repairs. Therefore, operational support for the facility will require 6 operator hours spread over two shifts per day, or 2190 operator hours per year. Average Operator time spent per wetlands test cell computes to 182.5 hours/cell/year. Including benefits, the hourly cost for a Wastewater Operator II is $12.86, or approximately $2347/cell/year, or $28,165 per year for a 12-cell facility.

Costs information for electrical power to operate facility sump pumps, and for materials and labor to repair or replace failed equipment, has not been developed by the consultant as of this writing. For purposes of this summary, electromechanical costs will be conservatively estimated as equal to personnel costs. Total estimated operations costs, then, are $4694/cell/year, or $56,328 per year for the planned 12-cell pilot facility.

Based on analytes and monitoring schedule proposed during charette discussions, along with others listed in the SWRP NPDES permit, the following draft wetlands facility monitoring protocol was prepared by City Public Works Department Technical Programs staff in conjunction with experts at the NBS and Reclamation in Denver. Analytical costs are based on the Albuquerque Water Quality Laboratory FY95 price list, assuming that one influent sample plus one sample per cell will be required for each sampling event. It should be noted that estimates have not been made for analyses of wetlands plant tissues, as recommended by charette participants.

The following table summarizes estimated facility costs for the 12-cell Constructed Wetlands Pilot Facility at the Albuquerque Southside Water Reclamation Plant.

	Design/Construct	Operations	Monitoring	Total Costs
Year 1	$547,992	$56,328	$149,904	$754,224
Year 2	--	$60,000	$170,000	$230,000
Year 3	--	$60,000	$170,000	$230,000

City of Albuquerque
Constructed Wetlands Pilot Facility
Draft Monitoring Schedule and Costs

Analyte Set	Cost/ Cell	Cost/ Series	Start Up (Jul)	Interim (Aug-Sep)	Stabilized (Oct-Jun)	Total Costs
Operating Parameters: Flow rate, H2O temp	N/A	N/A	Continuous	Continuous	Continuous	N/A
Water Chemistry: pH, DO (Eff)	$17	$204	2/week [$1768]	2/week [$3536]	2/week [$15,912]	$21,216
Solids: TSS (Inf, Eff)	$20	$240	4/month [$960]	2/month [$960]	2/month [$4320]	$6,240
Oxygen Demand: BOD (Inf, Eff)	$24	$288	4/month [$1152]	2/month [$1152]	2/month [$5184]	$7,488
Nitrogen: TKN, NH3+, NO2/NO3 (Inf, Eff)	$112	$1344	4/month [$5376]	2/month [$5376]	2/month [$24,192]	$34,944
Fecal Coli, Fecal Strep (Inf, Eff)	$114	$1368	N/A	N/A	1/month [$12,312]	$12,312
Hvy Metals: Al, Ag, As + 10 other (Inf, Eff)	$468	$5616	N/A	N/A	1/month [$50,544]	$50,544
Cyanide (Inf, Eff)	$90	$1080	N/A	N/A	1/month [$9,720]	$9,720
Sediment: 13 heavy metals + Cyanide	$310	$3720	1 Series [$3720]	N/A	1 Series [$3720]	$7,440
Total analytical costs			$12,976	$11,024	$125,904	$149,904

PILOT FACILITY PUBLICITY

Media coverage of the constructed wetlands pilot study began with a dedication ceremony and press conference June 21, hosted by Albuquerque Chief Administrative Officer Lawrence Rael and City Councilor Vickie Perea. Also attending was State Representative Pauline Gubbels who, during her tenure as an Albuquerque City Councilor, initiated the Constructed Wetlands Study Group. Considerable interest in the pilot facility has been expressed by NM State University, Los Alamos National Laboratories, the NM Waste Management Education and Research Consortium, and by out of state constructed wetlands firms. During the first two months of pilot facility operation, tours were conducted for groups from the Dona Ana Community College Water and Wastewater Program, the Public Works Finance Division and Sandia Pueblo.

PILOT FACILITY START-UP

Initial experimentation will be conducted in accordance with goals established during the January 1995 charette, under a memorandum of understanding currently being drafted between the City and the NBS. A monitoring plan, directed at evaluating pilot wetlands performance for metals removal and nitrogen kinetics, has been developed jointly between the two agencies (see draft monitoring schedule above). It is anticipated that the Albuquerque Water Quality Laboratory, located at the Southside Water Reclamation Plant, will provide analytical support for the project.

The City took possession of the Constructed Wetlands Pilot Facility June 30, 1995 and immediately introduced treated municipal wastewater effluent to the freshly planted test cells. Cells 7 and 8, in which no plants had been introduced, were temporarily left dry.

Plant Operations staff immediately encountered significant difficulties maintaining consistent flow rates to any of the 10 active test cells. Problems were initially attributed to clogging in the perforated PVC pipes that serve as influent distributors for each cell. While influent distributor clogging is a definite continuing problem, continued observation established that the primary facility feed pump, which pressurizes the main trunk of the test cells influent network, was operating outside its optimum range and regularly tripped its circuit breaker. Discussions with the design engineer established that higher flow rates were necessary to prevent automatic shutdown of the primary influent pump. To increase flow rates, influent was introduced to test cells 7 and 8, and an influent overflow valve was partially opened at the end of the primary influent line. Some improvements were observed in flow rate consistency, although the variable pipe diameters designed to provide differing influent flows to the test cells continued to create unpredictable interdependent flow rate effects.

Additional problems were encountered with test cell effluent sumps and pumps. In two deeper test cells (9 and 10), cell drain plug gaskets failed, allowing cell contents to enter the cell effluent sump without passing through the gravel bed and perforated PVC pipe collection system. A solution was developed, and repairs were accomplished by the Wastewater Division Maintenance Group, although it was necessary to completely drain the cells. Another problem was discovered when test cells 7 and 8 were brought online to correct influent flow rate inconsistencies. Effluent sumps for cells 7 and 8 each contain two parallel sump pumps, needed to evacuate the higher flow rates intended for these deeper cells. Unfortunately, check valves were omitted from the plumbing between the parallel pumps, causing one pump to force cell effluent backwards through the second pump. Consequently, one sump pump in each test cell was destroyed within 48 hours after cells 7 and 8 were brought on line. Further complicating the problems with test cell effluent discharge, it was discovered that the flow meters specified for effluent lines are extremely sensitive to clogging, and malfunction regularly. Plans were developed to retrofit fine mesh screens at test cell discharge pipes, in an attempt to exclude particulate material that might clog effluent meters.

Despite the mechanical difficulties described above, plants thrived in the pilot facility test cells. Monocultures planted in cells 3, 4, 5, 6, 9, 10, 11 and 12 were maintained by regular removal of sparse weeds, although nearly confluent growth of volunteer duckweed in most cells was tolerated. Joan Thullen, Research Botanist with the National Biological Service, visited the facility August 8-10,

1995 to collect initial plant density and health data. Ms. Thullen noted that plant communities in the test cells were much further developed than she had anticipated, based on her previous experiences with constructed wetlands in California and Colorado. In six weeks, Spikerush tufts had grown to over 100 stems per square foot and Bulrush had reached nearly 6 feet in height. Moreover, habitat components of the pilot facility had become evident, with such indicators as a burgeoning dragonfly population, a diversity of subsurface insect life and regular visits by ducks and their broods. In anticipation of an eventual need to suppress mosquito breeding, the introduction of indigenous species of minnows and bats is being explored with local experts with the U.S. Fish and Wildlife Service and the National Biological Service.

APPENDIX A

Albuquerque Constructed Wetlands Pilot Facility Handouts Prepared for BCESGRT Advisory Board, November, 1994--Not included here.

APPENDIX B

Albuquerque Constructed Wetlands Pilot Facility National Biological Service/US Bureau of Reclamation Final Conceptual Design Proposal, November, 1994--Not included here.

APPENDIX C

Albuquerque Constructed Wetlands Pilot Facility Charette January 21, 1995, Summary--Not included here.

APPENDIX D

Albuquerque Constructed Wetlands Pilot Facility Written Opinions Received--Not included here.

Riparian restoration of Señorito Canyon, a tributary of the Rio Puerco

Dwain W. Vincent[1]

Abstract.—Señorito Canyon, a non-functional, degraded tributary stream of the Rio Puerco in New Mexico, has begun to respond to management strategies by the Bureau of Land Management. Restoration of the riparian ecosystem has been accomplished principally through livestock grazing management and planting and reestablishment of the native cottonwood/willow communities. The use of riparian pastures constructed along the stream was necessary to "jump-start" the system and allow total grazing deferment from 3 to 5 years.

INTRODUCTION

Señorito Canyon is one of the few, perennial flow, tributaries of the Rio Puerco in New Mexico. The Rio Puerco produces large quantities of sediment and flows into the Rio Grande, which is one of the most polluted rivers in the southwest.

The confluence of the Rio Puerco and Señorito Canyon is located approximately five miles south of Cuba, N.M., and has 34,087 acres of watershed above this point. The headwaters located on the Santa Fe National Forest are 11 miles upstream at over 9,000 feet in elevation in the Fir-Aspen zone.

The BLM manages the lower elevation or the furthest downstream reach of this stream (approximately 3 miles). This reach ranges from 6,680 to 6,800 feet in elevation. The channel sinuosity ratio is 1.19. The stream width ranges from 36 to 47 inches and depth is 4-12 inches at low flow. The width of the riparian area ranges from 119 feet in the upper portions to 171 feet further downstream.

[1] *Natural Resource Specialist, Bureau of Land Management, Albuquerque, New Mexico.*

ENVIRONMENTAL SETTING

The watershed drains a portion of the Nacimiento Uplift, which are Precambrium, plutonic, igneous rocks overlain by Permian and Triassic sedimentary rocks. Low lying hills along the margins of the valley further downstream are composed of Createous Lewis shale, a marine shale that forms the "bedrock" in the stream channel area.

The soils along the streambank are Navajo clay. This is an Entisol, Typic Torriorthent, fine, mixed, calcareous, mesic. The A horizon (0-16 inches) is reddish brown sandy clay loam to clay loam with granular to angular blocky structure. The C horizon (16-31 inches) is very heavy dense clay with a weak, fine, blocky structure. This soil contains much salt with vertical cracks or "piping" common. It has a high shrink-swell potential and a reaction of 8.5 to 9.0 PH. The permeability is slow and water holding capacity is high. The hydrologic soil group is D.

The BLM managed segment has a mean annual precipitation of 13.45 inches, with a frost free period precipitation of 7 inches. The mean number of frost free days is 140 (approximately May 10 to September 25).

A monthly hydrograph of Señorito Canyon shows a peak runoff in May with a mean of 119 cfs. This represents the snowmelt period. A second smaller peak in August of 18 cfs, represents the mean from summer thunderstorms. Summer flash floods have ranged from 130 to 2,360 cfs.

The lower, BLM managed areas adjacent to the riparian zone have a dominant vegetative cover of black greasewood *Sarcobatus vermiculatus,* shadscale *Atriplex confertifolia* and basin big sagebrush *Artemisia tridentata* tridentata. The herbaceous understory is dominated by alkali sacaton *Sporobolus airoides.*

At the present time, the BLM managed segment of the riparian stream habitat is 22% non-functional and 78% functional at risk. The trend has been upward for the last four years (1990-1994).

Elliott (1979) devised a hypothetical sequence of arroyo evolution for the Rio Puerco and its tributaries. Señorito Canyon ranges from stage B to C in the BLM reach (refer to figure 1).

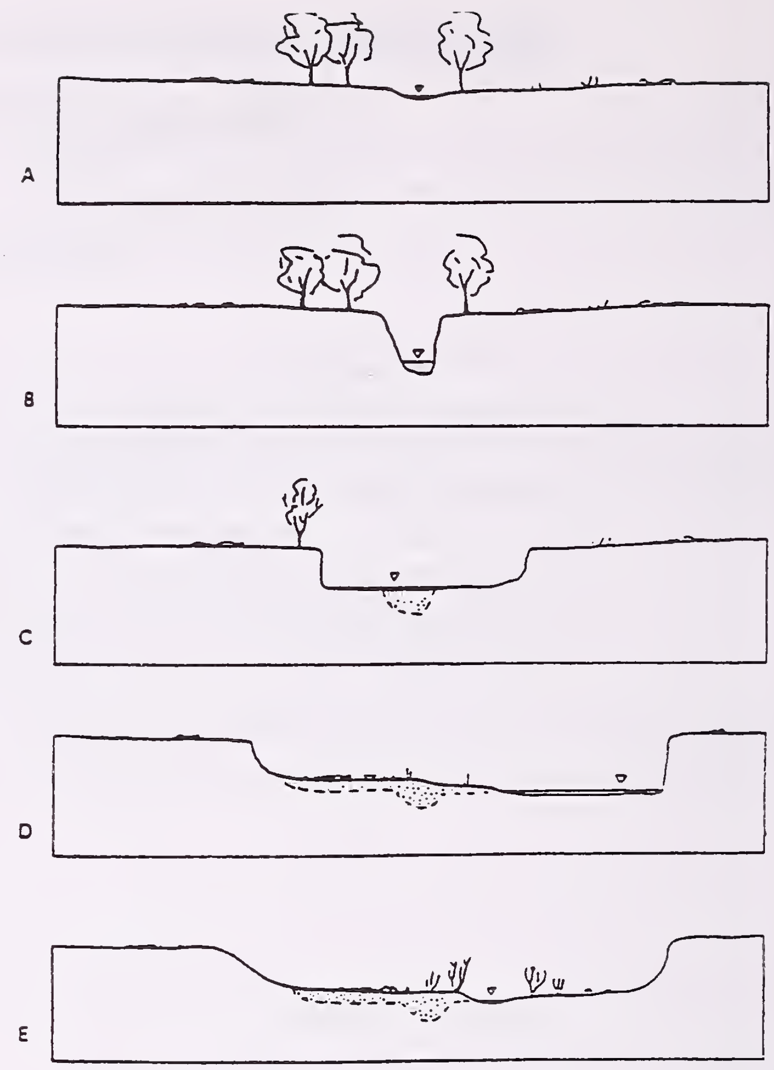


Figure 1. Hypothetical sequence of arroyo evolution. (Elliott, 1979).

HISTORICAL RECORD

It is estimated that the last downcutting of the Rio Puerco and its tributaries began between 1885 and 1890. The Señorito Canyon stream channel has been downcut 10-20 feet through the alluvium and the water table has subsequently dropped. This has allowed upland species to invade the riparian zone such as rabbitbrush and sagebrush, During the 1920's and 1930's, salt cedar *Tamarix spp.* was planted by the Soil Conservation Service for the purpose of streambank stabilization. Since that time it has spread the entire length of the lower Señorito Canyon. Another non-native, Russian olive *Elaegnus angustifolium* has also begun to invade the riparian zone.

Historically, the Rio Puerco and its tributaries, such as Señorito Canyon, supported a native riparian plant community of a gallery overstory of Fremont cottonwood *Populus fremontii.* Associated species included coyote willow *Salix exigua,* fendler rose *Rosa woodsii,* New Mexico locust *Robinia neomexicana,* Desert olive *Forestiera neomexicana,* and other woody species. The understory was a mixture of sedges, rushes and aquatics such as horsetail *Equisetum spp.* and cattail *Typha spp.*. The coyote willow still occur, but have been replaced to a large degree by salt cedar.

The gallery forests of Fremont cottonwood which once covered the Rio Puerco floodplains and its tributaries, were often close to early settlements. Trees were cut for fuel, ceiling beams "vegas" for adobe buildings and to clear land for agriculture and urbanization. Beaver *Castor canadensis* have also cut down cottonwoods. The benches and terraces of the Rio Puerco and its tributaries such as Señorito Canyon, when flooded, cause cottonwoods to sprout. The seedlings are highly relished by cattle and are browsed along with the willows. During the 1990 inventory of Señorito Canyon, only one cottonwood was found on the reach managed by BLM, State, and private land owners (approximately 6 miles).

Historically the riparian area has been grazed heavily and continuously yearlong. The BLM segment of the stream flows through three grazing allotments. Cattle concentrated along the stream because of the obvious shade, succulent feed and

perennial water supply. This has severely restricted cottonwood and willow regeneration.

The native cottonwood/willow communities, once common along the Rio Puerco and its tributaries are now threatened. As the few old trees (80-100 years) die they are not being replaced and reproduction is low.

Cottonwoods are considered a "keystone" species because so many other plants and animals depend upon them. Their large size provides a canopy habitat that serve raptors, cavity nesters, and neo-tropical migrants.

WILDLIFE HABITAT

Managing riparian habitat for wildlife has drawn a great deal of interest in the past few years. Riparian habitat is especially important to neotropical migrant birds, which are declining over much of their ranges. The Partners in Flight/Aves de las Americas Neotropical Migratory Bird Conservation Program is a commitment to conserve these species and their habitats.

The Rio Grande Basin, which includes the Rio Puerco and its tributaries has been identified as part of the historical range of several neotropical birds on the decline. The southwestern willow flycatcher *Epidonax traillii extimus* is one of these. It winters in southern Mexico south to Panama and occurs in the western side of New Mexico during the spring and autumn migration and are known to breed in the Rio Grande Basin. These birds are confined to riparian woodlands. They need a cottonwood overstory with a willow understory with nearby areas of surface water (preferably slow flowing).

The southwest willow flycatcher has suffered from loss of riparian habitat or a degradation of the habitat and has further declined due to the brown-headed cowbird *Molothrus ater*. This bird, the original buffalo bird of the plains, is a parasitic breeder. It lays its eggs in the nest of songbirds including the SW willow flycatcher ends up raising cowbirds.

MANAGEMENT PLAN

In 1990, a cooperative resource management plan was developed with the private land owners, U.S. Forest Service, Soil Conservation Service, New Mexico State Land Office and Bureau of Land Management. This plan was intended to better manage the entire watershed with emphasis on the riparian zone.

The reach of Señorito Canyon managed by BLM have the following general objectives:

- Improve diversity and productivity of the riparian plant communities.
- Improve water storage and restore ground water table.
- Improve water quality.
- Reduce peak flow velocities and the impacts of flooding.
- Reduce upland tap rooted shrubs that have invaded riparian area.
- Increase available water to native hydrophytes by controlling salt cedar.
- Improve wildlife habitat for migrant ave-fauna, aquatic macroinvertebrates, fish, obligate and facultative amphibians, reptiles and mammals.
- Provide a dependable and nutritional source of livestock forage for wintering cattle.
- Improve watershed conditions on the adjacent uplands by reducing sheet erosion caused by overland flow.

After the initial inventory and establishment of monitoring studies specific objectives were proposed:

- Increase the dominance of preferred plant communities by 20% five years after plan implementation. Preferred communities were:
  - *Salix exigua/Melilotus alba* or *M. officinalis*
  - *Populus fremontii/Salix exigua/Carex spp.*
- Reduce the dominance accordingly of *Tamarix/Chrysothamnus/Artemisia*. Maintain the width/depth ratio of 9.29 on the Forty Four allotment segment and 13.3 on the Señorito Allotment segment.

RECOMMENDATIONS

- Leave an adequate carryover vegetation for bank protection and sediment filtering during spring snowmelt and summer floods.

- Provide a structural layering of cottonwoods and willows with several age classes to provide shading, nest building, perching, ready access to water and escape cover for wildlife.
- Plant cottonwoods, willows and other native, woody species to act as buffers of peak run-offs on stream banks and flood energy dissipators.
- Develop a grazing scheme to allow for increased germination, sprouting and seedling survival for riparian vegetation.
- Slow runoff velocities and catch sediment from sheet erosion from adjacent uplands.

PROPOSED ACTIONS

- Construct five riparian pastures approximately 10 to 20 acres in size.
- Plant cottonwood poles, sprig willows, and plant root stalk riparian species in all five riparian pastures.
- Spray salt cedar with Isopropylamine salt of imozapyr (Arsenal or Chopper), Spray approximately 5-10 acres per year for 5 years.
- Defer livestock grazing from 3-5 years (no grazing) until desired riparian vegetation is established and stream banks are stabilized and the riparian area is functioning properly. Grazing will then be allowed only during the dormant season (October 15 to March 31).

MONITORING

The BLM is using false color infrared photos 1:4800 scale, that were flown in July of 1991. This will be the baseline and will be flown every 5 years to help monitor the riparian vegetation and stream channel. The more subtle changes will be detected using the green line vegetative monitoring. The green line is a .1 acre area 363 feet on each side of the stream (726 feet) and 6 feet wide. There are three cross sections in each 0.1 acre area that measure channel width and depth plus width of each vegetative community across the entire riparian area. The number and age class of woody species are also counted and the amount of bank overhang. Nine photo points are also established at the three cross sections. The BLM also began macroinvertebrate sampling in 1993. This baseline data will be another indicator of water quality.

RESULTS

Water gap fencing was constructed between each of the five riparian pastures. Cattle have a 300-600 ft. wide access to the stream between each pasture. Panels of (PE) polyethylene pipe were hung on a cable stretched across the channel.

Cottonwood poles (12-14 feet) and willows were planted along with some root stalk of other riparian species. Holes were augured down to the water table 3 to 4.5 feet, depending on the distance away from the channel. More than 100 cottonwoods and over 300 willows were planted. Planting occurred during the last week in March. By June they had begun to leaf out. By August they began to look like a tree with branching and leaves. By September, sprouting willows were showing up that we didn't plant. Planting was done with the aid of volunteers from the Southwestern Indian Polytechnic Institute.

The channel of Señorito Canyon shows initial stages of meandering in the upper reaches and advanced sections further downstream. By midsummer of 1993, nine months after the first four riparian pastures were constructed, we had a great deal of channel narrowing by vegetation. This was principally an increase in sedges, white and yellow sweet clovers and coyote willows.

After two large flash flows during the summer of 1993, the velocity of the stream flow was noticeably slowed as evidence of bent over vegetation and litter accumulation. There were also several inches of sediment deposited along the channel. Channel aggradation has begun to occur.

CONCLUSIONS

The Rio Puerco and its tributaries have lost much of their ecosystem integrity. This is evident in the low diversity, present riparian vegetative communities and the wildlife they support. Native species of cottonwoods, willows and sedges have

been replaced by exotic invaders such as salt cedar, Russian olive and sweet clovers. This loss of native species has caused a reduction in biological diversity of plant and animal species. Only fragmented stands of cottonwood/willow stands are now found along stream banks. We hope to change Señorito Canyon from poor riparian condition rating to high and bring the riparian areas rated as non-functional and functional at risk to proper functioning condition.

REFERENCES

American Fisheries Society, Western Division, August 1982. The Best Management Practices For The Management And Protection Of Western Riparian Stream Ecosystems.

Asplund, Kenneth and Michael T. Gooch, May 1989. Geomorphology And The Distributional Ecology Of Fremont Cottonwood *Populus fremontii In* A Desert Riparian Canyon, Prescott College, Prescott, Arizona.

Batson, Fred T., Paul E. Cuplin and Wallace A. Crisco, USDI, BLM, August 1987. The Use Of Aerial Photography To Inventory And Monitor Riparian Areas, Tech. Reference 1732-2, BLM Service Center, P.O. Box 25047, Denver, CO.

Cagney, James A., November 1989. Functions Of Vegetation, And Methods Of Quantification In Riparian Systems, USDI, BLM, Ruidoso, N.M.

Cagney, James A., 1993. Greenline Riparian-Wetland Monitoring, USDI, BLM, Tech. Ref. 1737-8, BLM Service Center, P.O. Box 25047, Denver, CO.

Clary, Warren P. and Bert F. Webster, USDA, USFS, Intermountain Research Station, May 1989. Managing Grazing Of Riparian Areas *In* The Intermountain Region, General Tech. Report INT-263.

Clary, Warren P. and Bert F. Webster, August 1990. Riparian Grazing Guidelines For The Intermountain Region, Rangelands, 12 (4).

De Bano, Leonard F. and Larry J. Schmidt, USDA, Rocky Mt. For. And Range Expt. Sta., December 1989. Improving Southwestern Riparian Areas Through Watershed Management, General Tech. Report RM-182, Fort Collins, CO.

Elmore, Wayne and Robert L. Beschta, December 1987. Riparian Areas: Perceptions In Management, Rangelands Vol. No. 9 (6).

Hafner, Dr. David J., 1988. Characteristic Mammals Of Riparian Systems, New Mexico Museum Of Natural History, Albuquerque, N.M..

Jones, Bruce K., January 1989. Symposium—Principles Of Wildlife Habitat Management In The Riparian And Wetland Ecosystem, Amphibians And Reptiles, Las Cruces, N.M.

Kerpez, Theodore A. and Normon S. Smith, 1987. Saltcedar Control For Wildlife Habitat Improvement In The Southwestern United States, USDI, Fish And Wildlife Service, Resource Publication 169, Washington, D.C.

Kinch, Gene, September 1989. Riparian Area Management, Grazing Management In Riparian Areas, BLM Technical Reference No. 1737-4, BLM Service Center, P.O. Box 25047, Denver, CO.

Knopf, Fritz L., et. al., 1988. Conservation Of Riparian Ecosystems In The United States, Wilson Bull. 100 (2), pp.272-284.

McLemore etal, 1984. Bureau Of Mines And Mineral Resources, Open File Report 211, Socorro, New Mexico.

Myers, Lewis H., May 1989. Grazing And Riparian Management In Southwestern Montana, BLM, Riparian Resource Management Workshop, Dillon, Montana.

Myers, Lewis H., July 1989. Riparian Area Management-Inventory And Monitoring Riparian Areas, USDI, BLM Tech. Ref. 1737-3, BLM Service Center, P.O. Box 25047, Denver, CO.

Peddie, Dr. William A. 1993. New Mexico Vegetation-Past, Present And Future, University Of New Mexico Press, Albuquerque, N.M.

Prichard, Don, Etal, 1993. Process For Assessing Proper Functioning Condition, USDI, BLM Work Group, BLM Service Center, P.O. Box 25047, Denver, CO.

Rosgen, David L., April 1985. A Stream Classification System, Paper presented at The North American Riparian Conference, Tucson, Arizona.

Szaro, Robert C., 1989. USDA, USFS, Riparian Forest And Scrubland Types Of Arizona And New Mexico, Desert Plants, Vol. 9, No. 3-4.

Szaro, Robert C. Etal, 1985. Impact Of Grazing On A Riparian Garter Snake, Symposium—Riparian Ecosystems And Their Management: Reconciling Conflicting Uses, Tucson, Arizona.

USDA, U.S. Forest Service, 1985. Riparian Ecosystems And Their Management: Reconciling Conflicting Uses, General Tech. Rep. RM-120, First North American Riparian Conference, Tucson, Arizona.

Using simple structures for flow dispersion in wet meadow restoration

Bill Zeedyk[1], Benjamin Romero[2], and Steven K. Albert[3]

Abstract.—Historically, wet meadow recovery projects have relied on heavy earth moving equipment to harden nick points and install gully plugs or terraces to trap and detain sediments. We experimented with a variety of simple hand-built structures fashioned of logs, rocks, geotextile fabrics and/or sandbags designed to disperse runoff, rewet surface and subsurface soils and stimulate the growth of wetland dependent vegetation adapted to erosion control and sediment detention. We utilized workers from a variety of labor pools to implement projects.

INTRODUCTION

Wet meadows are riparian grasslands having low velocity surface and subsurface flows, hydric soils and wetland dependent vegetation dominated by grasses and grass-like plants. Wet meadow vegetation requires soil moisture in excess of that available from direct on-site precipitation alone. Well dispersed runoff originating from upslope or groundwater sources is essential to wet meadow function. Surface irregularities, such as rills and gullies resulting from accelerating soil erosion, impede wet meadow functions by progressively constraining the dispersion of surface and subsurface flows originating from off-site sources and draining moisture from adjacent areas by capillary action.

Historically, wet meadow restoration projects have attempted to reclaim damaged sites by using costly erosion control devices, such as hardened nick points, sediment traps, dams and terraces. Usually construction is accomplished using expensive earth moving equipment. Few projects have focused on flow dispersion as the primary treatment.

[1] *Zeedyk Consulting Services, Sandia Park, New Mexico.*

[2] *Wildlife Biologist, Tres Piedras Ranger District, Carson National Forest.*

[3] *Director, Fish and Wildlife Department, Zuni Pueblo.*

OBJECTIVES

We attempted to bring about wet meadow recovery by improving the dispersion of surface and subsurface flows using simple, hand-built structures. Our goal was to secure conditions favoring natural ecological processes. Primarily we wished to stimulate the growth of wetland dependent and wetland faculative plants, such as sedges and rushes because wetland vegetation has the ability to retard runoff, increase rates of infiltration and percolation, trap and retain sediments, assimilate nutrients and is self perpetuating.

Primary objectives were to:

1. Disperse surface flows and expand the area periodically saturated by seasonal runoff.
2. Extend the duration of seasonally available soil moisture.
3. Stimulate colonization by wetland vegetation and increase plant densities.

Secondary objectives were to:

1. Control and prevent soil erosion through increased vegetative cover.
2. Detain and retain sediments through vegetational filtering and bonding.

METHODS

Beginning September 1993, various simple labor-intensive structures fashioned of geotextile fabric, logs, rocks and/or sandbags were installed on Cibola National Forest, Carson National Forest, wet meadow sites, and Zuni Pueblo. Labor was provided from a variety of human resource programs, volunteer organizations and agency programs. We purposefully ruled out the use of earth moving equipment in order to test the feasibility of hand-built structures and to minimize soil compaction.

Structure types and locations were identified and flagged prior to construction, placing emphasis on the primary objectives of flow dispersion and extended soil moisture availability, therefore we selected sites where flows could be easily dispersed over wider areas.

Structure types included log structures, with and without geotextile fabrics, sandbag structures one and two tiers high in various arrangements, rock structures with and without geotextile fabrics, and log or rock structures faced with sandbags. All log structures were installed with logs placed parallel with channel flow to minimize scour pool formation and end cutting. Two types of geotextile fabrics were tested.

Evaluation and monitoring was by visual examination and photo documentation conducted at the end of each growing season and immediately following spring runoff. We examined structural performance, vegetative response, extent of surface wetting and sediment accumulation.

RESULTS

Results have been variable due not only to variations in structure types and applications, but also to local vagaries in precipitation, soil types, vegetation composition, watershed characteristics and other factors.

- Flow dispersion objectives have been met and soil moisture is increasing.
- The duration of seasonal wetting has been extended especially where sand bags were incorporated into structure design.
- Wetland plants have increased in density and have colonized many treated sites.
- Sediment deposition is occurring as channel roughness increases with increasing plant densities and stubble heights.
- As sediment accumulates in treated channels, more frequent overbank spilling is occurring further expanding the wetted soil surface.
- Sandbag structures have been easier to install than either log or rock structures and can be readily modified as needed in response to changing patterns of flow or erosion.
- Results derived from the use of geotextile fabrics have been mixed. The benefits of increased sediment capture have been offset by the suppression of vegetation growth. Silt fencing fabrics, used without stakes or wire reinforcement, have been effective and convenient to use.

DISCUSSION

We have noted an obvious increase in plant densities and vigor within a year of structure installation at most sites. The primary objectives of increased flow dispersion, surface wetting and duration of wetting are being realized.

Sandbag or sandbag-faced structures seemed to be more effective than log or rock structures alone, especially where vegetation is sparse.

Lower structures perform better than taller structures, being less prone to damage by end cutting, under cutting or scouring.

The use of volunteers enlisted from citizen conservation organizations has proven beneficial not only in numbers of treatments installed, but also in increased enthusiasm for wetland restoration.

Little maintenance has been required, or if needed, has been easily performed with hand labor.

ACKNOWLEDGMENTS

The authors appreciate the administrative support extended by District Ranger Dan Rael, Carson National Forest, and Project Leader, Jim Enote, Zuni Conservation Project. We especially appreciate the dedication and enthusiasm extended by Technicians Nelson Luna and Vernon Quam, Zuni Fish and Wildlife Department, who coordinated activities of Zuni Restoration Crews. Wildlife Biologist Jim Anderson, formerly of Cibola National Forest, coordinated construction at La Ciengita.

Restoration guidelines for riparian areas using dormant stock "pole" cuttings

Tony Barron[1]

Abstract.—The Open Space Division manages seven thousand acres of riparian areas comprising the Rio Grande Valley State Park. In 1988, Open Space began experimenting with dormant stock cuttings. This paper contains methods and procedures for establishing dormant stock cuttings. Dormant stock cuttings will be referred to as "poles" in this paper.

The Open Space Division manages seven thousand acres of Riparian areas comprising the Rio Grande Valley State Park. In 1988, Open Space began experimenting with dormant stock cuttings. This paper contains methods and procedures for establishing dormant stock cuttings. Dormant stock cuttings will be referred to as "Poles" in this paper.

CATEGORIES OF POLES

Category I — Young trees 2-4 years old found growing in Riparian areas.
Category II — Cuttings taken from older established trees (10 years and older.)
Category III — Young trees 2-4 years old grown by nurseries or private enterprises.

METHODS

One of our management goals is to restore the riparian areas that have been disturbed using dormant cuttings, pole plantings and re-vegetation techniques applicable to riparian areas.

During the early stages of our experimentation Category II poles showed extremely high mortality rates. Collection was labor intensive. It was very difficult to locate straight stock in adequate lengths for planting.

Category I and III poles are recommended based on data collected and results derived from plantings of the above categories. Dormant stock cuttings from Black Willow (Salix goodingii) and Fremont Cottonwood (Populus fremontii) were used for the majority of our plantings. Lance leaf (Populus acuminata)and other hybrids as well as varieties occurring naturally in riparian areas were also planted and monitored.

DORMANT STOCK OR "POLE" COLLECTION PROCEDURES

Pole plantings have been used for several decades, however, these plantings are very popular today due to successful plantings.

Collection of poles (Category I) should be performed under direct supervision using trained personnel. Knowledge of species, ability to identify stock, and collection and storage procedures are necessary. Site selection should be made by qualified Resource Managers.

Category III poles offer many advantages for governmental agencies and their co-operators. Selection and collection are easily accommodated as options for pick-up and delivery are available. Contact local Soil Conservation Service Land Management Agencies or write to address on this publication for information.

[1] *Operations Manager, City of Albuquerque, Park & General Services Department, Open Space Division, P.O. Box 1293, Albuquerque, NM 87103.*

POLE STORAGE

Most times poles will require storage. Both Categories I and III should be stored soaked in water within 24 hours of collection in a shaded and cool area. Depending on planting schedules, poles should be rotated and the water monitored, refreshed and changed weekly. Large barrels or water troughs are commonly used for storage.

Testing has shown no need for root stimulator or other agents. Soaking poles in fresh water and following the above procedures will yield excellent stock for planting. Poles can be stored up to ninety days, depending on conditions.

MONITORING WELLS

It is good practice to install a monitoring wells one year before the planting process begins. These wells can cover 1-5 acre sites depending on site variations in land elevations. During the one year period before the planting process, fluctuations in the water table are monitored and recorded along with other testing as deemed necessary by Project and/or Resource Managers.

POLE PLANTING PROCEDURES

Augers attached to a bobcat and backhoe respectively were used to drill to depths from seven and a half feet to fifteen feet for deeper pole installations. Optional tools and related planting equipment include axe, auger (hand bucket type), auger extensions, machete, measuring pole (20 ft), plastic tree guards, stakes, labels, wire (for caging), hammer, saw, pruners, and field notebook.

After mechanical drilling, poles are immediately installed with additional hand auguring often being required. The Butts or bottoms of poles are diagonally cut to a point. Scoring is performed 12" to 18" upwards from bottom of pole using axe or machete. When practical, poles should be installed 12" or more into the water table. Back filling of holes is recommended to eliminate air pockets.

PROTECTION OF POLE PLANTINGS

Beaver and other smaller animals should be considered when planting poles. Common methods of protection used by the Open Space Division range from "Vet Wrap," plastic "spiral" tree guards, and woven wire are used for young and established trees. The Project and/or Resource Manager should determine the proper devices to be used at each site location.

MONITORING

Monitoring must be conducted to facilitate high rates of survival. Because most riparian areas are remote with limited access, managers should develop a data base to monitor and study the progress. To plant and walk away is not a cost-effective management option. A monitoring program is recommended for all dormant stock "pole plantings."

RESULTS AND SURVIVAL RATES

After initial plantings, data collected has yielded the following survival rates after four years of monitoring:

- Cottonwood - 92% survival rate
- Black Willow - 98% survival rate
- Overall survival rate was 95%

CONCLUSIONS AND COMMENTS

Dormant stock or pole plantings have proved to be the most cost-effective method to-date to restore riparian areas with Cottonwood and Black Willow trees. All protection devices worked excellently. Training is required for all personnel in collection, planting, and on-going monitoring. A monitoring program of a minimum of three years is recommended. Opportunity exists for further expansion and production within the private sector.

Restoring native riparian vegetation

Debbie Hughes[1]

Abstract.—In the lower Pecos Basin, an unusual coalition of conservationists, agriculture producers, business owners, and state agencies have joined together to save what is left of the once-naturally diverse Pecos River ecosystem. This organization is going to show a state-of-the-art, economical, effective, efficient, and environmentally safe method to control salt cedar and reestablish native riparian vegetation. The objectives of the project are to demonstrate native wetlands and wildlife habitat improvement through salt cedar management; to demonstrate effective, economical, and environmentally sound salt cedar control; and to monitor possible hydrologic effects from salt cedar control and management.

The spread of salt cedar in the Pecos River Basin has been phenomenal since the turn of the century. Estimates are that it has replaced 75,000 to 100,000 acres of native riparian vegetation, thus displacing native wildlife species by eliminating their habitat. The Pecos River Flood Plains has, in effect, become a one-species thicket providing limited habitat for wildlife. A large salt cedar can transpire as much as 200 gallons of water per day - or about the amount a family uses each day. The loss of water resources costs New Mexico millions of gallons of water annually, but the value of the natural diversity loss to the ecosystem cannot be measured. This increase in. Salt cedar is common along all major rivers in the Southwest United States.

In the lower Pecos Basin an unusual coalition of conservationists, agriculture producers, business owners and state agencies has joined together to save what is left of the once-naturally diverse Pecos River ecosystem. Rather than depending on state or federal agencies to take the lead in dealing with the problem, this coalition has formed a non-profit corporation made up of four soil and water conservation districts: the Carlsbad SWCD, Central Valley SWCD, Penasco SWCD and Dexter-Hagerman SWCD; along with the Pecos Valley Artesian Conservancy District and the Carlsbad Irrigation District. Each entity has a representative on the Board of Directors who volunteers their time toward this project. This organization is going to show a state-of-the-art, economical, effective, efficient and environmentally safe method to control salt cedar and reestablish native riparian vegetation. We have enlisted the help of Dr. Keith Duncan, New Mexico State University, Weed and Brush Control Specialist.

The objectives of the demonstration are:

1. To demonstrate native wetlands and wildlife habitat improvement through salt cedar management;
2. To demonstrate effective, economical and environmentally sound salt cedar control;
3. To monitor possible hydrologic effects from salt cedar control and management.

The demonstration area is along the Pecos River east of Artesia, New Mexico. The area begins just south of the Artesia bridge where US highway 82 crosses the Pecos River and runs a little over six miles in a southerly direction along the west side of the Pecos River at the northern end of an area known as the McMillan delta.

[1] *Pecos River Restoration, 163 Trail Canyon Road, Carlsbad, NM.*

An integrated approach of mechanical and herbicide treatment is being used to manage the salt cedar. The herbicide application methods have been aerially applied according to EPA labeling and under the supervision of the New Mexico State University Extention Service and the New Mexico Department of Agriculture. The mechanical treatment has been done by dozing and root plowing the salt cedar in and around the remnant stands of cottonwoods and black willows. The remaining stumps were treated by hand with Arsenal.

Re-sprouts that appear in the following growing season have been treated individually with a tank mixture of Arsenal and Round-Up. Most of the project area supports a heavy, dense stand of salt cedar. These expansive areas of dense salt cedar have been aerially treated with a combination of Arsenal and Round-Up. A 100-foot buffer zone was left along the river and will act to prevent drift from reaching the river. Areas of scattered salt cedar, found at the project area fringes and where significant stands of native vegetation are present, will be treated with ground-based foliar applications of Arsenal and Round-Up, or by cut-stump treatments with Arsenal.

Follow-up measures utilizing prescribed burning and mechanical clearing will be used to remove the remaining salt cedar once the native vegetation has been reestablished. Several different species of plants and methods of re-vegetation are planned depending on the soils and vegetative sites. In some areas, the dead salt cedar plants may be left standing to provide soil stability and wildlife cover. A delay in follow-up practices to remove the dead salt cedar will insure ample vegetative ground cover to protect against possible soil erosion once the standing, dead salt cedar is removed.

A properly designed and conducted program will have minimal long-term negative impacts on fish and wildlife resources in the area. Short-term losses of habitat could result in decreases or relocation of local populations of some species, but a proper re-vegetation program will allow a quick recovery. Additional habitat diversity, numerous species of native vegetation vs. a monoculture of salt cedar will have a positive long-term impact on native plant and wildlife populations.

The re-vegetation plan developed by the Natural Resourses Conservation Service, based on soil types, soil quality, water availability and quality will be implemented as a post-treatment activity. The New Mexico State University Fisheries and Wildlife Department, in conjunction with the New Mexico Game and Fish Department, will conduct pre and post treatment surveys of all wildlife species found within the treated area with a control area being sampled outside the treated area.

The proposed management and program activities will continue over a period of about ten years. From the very beginning, we have involved all interested parties, from agriculture industry groups to environmental groups. The Natural Resources Conservation Service has provided leadership to our organization in the development of an environmental assessment (EA) of the proposed actions and a plan based on the alternatives that are available. The EA team was structured to represent all interested parties such as the U.S. Fish and Wildlife Service, the New Mexico Environment Department and the New Mexico Department of Game & Fish.

This corporation has been able to help secure federal funds that are being administered by the Natural Resources Conservation Service to the Central Valley Soil and Water Conservation District for the soil, water, vegetation and wildlife studies as well as all re-vegetation activities. Funds have been appropriated by the New Mexico State Legislature for the removal of the salt cedar and are being administered by the New Mexico Energy and Minerals Department, Forestry Division, through a Joint Powers Agreement with the Central Valley Soil and Water Conservation District. Additional private funding sources have also been secured to initiate the development of the project plan. Countless volunteer hours have gone toward the process of making this project a reality. Meetings have taken place for four years working to include any interested or effected parties. The group has sponsored field trips to the project area and testified before Interim Legislative committees. It is very important in the beginning of the process to package or present your ideas for the project area in an acceptable manner that is not offensive to any one group. Being able to find common ground should be your focus.

A great impact on the Pecos River Basin resulted from the U.S. Supreme Court ruling in Texas v. New Mexico. The Supreme Court amended the 1947 Pecos River Compact placing more stringent

requirements on the State of New Mexico to deliver water to Texas. The economic benefits of this project really come into play if this project can demonstrate that water can be salvaged as the dense stands of salt cedar are replaced by native riparian vegetation and additional water accrues to the river.

The project is a great opportunity to demonstrate modern integrated techniques in the management of salt cedar and reestablish native riparian vegetation, which is applicable to all of the river valleys of New Mexico and throughout the Southwest. But more important, it shows how concerned citizens can work together to gain the cooperation of the government agencies to solve their own problems.

In today's world of tight budgets and a wider diversity of people who are interested in our work, it requires more creativity in how we work with people to meet their needs. The benefits of our technology and programs, and how to help solve environmental issues, must be stressed in different ways with many types of customers-agricultural, environmental, legislative, business and others who can benefit by working with us. Marketing our Conservation Services is going to help the conservation partnership. As state and federal funding sources are being reduced in the future, this is the kind of partnership we need statewide to take care of other problems and help protect New Mexico's Renewable Natural Resources.

Mitigation in riparian areas: Questions, concerns and recommendations

Tony Barron[1]

Abstract.—The management of seven thousand acres in the Rio Grande Valley State Park presents a unique management challenge and opportunity. The Open Space Division defines a riparian area as "any area of land influenced directly by permanent water". The influence of permanent water or water flows produces visible vegetation and visible vegetative characteristics on the affected land. The Open Space Division management practices are designed to avoid adverse and negative impacts as much as possible. Mitigation measures such as creating wetland, land donation (including beneficial land exchanges and monetary/compensatory measurers) are encouraged. This paper addresses questions about mitigation procedures.

The Management of seven thousand acres in the Rio Grande Valley State Park presents a unique management challenge and opportunity. The Open Space Division defines Riparian areas as "any area of land influenced directly by permanent water."The influence of this permanent water or water flows produces visible vegetation and visible vegetative characteristics on the affected land by this water influence or presence.

Our riparian areas yield a lush green bosque bordering the great Rio Grande River and are some of the most valued areas entrusted to the Open Space Division to manage.

In order for the Open Space Division to achieve their goals and objectives, funding, support and agency co-operation are necessary. Among our major management goals is the protection of Riparian Areas. We attempt to avoid or keep to a minimum negative, and costly impacts using mitigation agreements or other compensatory actions.

[1] *Operations Manager, City of Albuquerque, Park & General Services Department, Open Space Division, P.O. Box 1293, Albuquerque, NM 87103.*

The Open Space Division management practices are designed to avoid adverse and negative impacts as much as possible. Unavoidable impacts are common and must be minimized and mitigated appropriately. Mitigation measures such as creating wetlands, land donations including beneficial land exchanges and monetary, compensatory measures are encouraged.

When established trees and vegetation are removed, they must be replaced satisfactorily. Replacement of trees and vegetation should include a minimum of three years of monitoring. This monitoring documents the success rate and the success of the mitigation agreements.

Question: Can 40 or 50 year old trees be mitigated with planting 3, 5, or 10 dormant stock cuttings without any monitoring efforts?

Answer: Due to the extensive established root system and age, the older tree will live longer as conditions exist. Newly planted poles or cuttings must be monitored to document their survival rates. Protection must be provided from beaver other possible infestations.

The re-establishment of the desired plant community is also needed and should be included in

the mitigation process. Inventories should be performed by a Project and/or Resource Manager.

Monetary values should be assigned to trees based on a standardized appraisal method. Shrubs and other vegetation can be replaced using 2:1, 3:1 or applicable replacement ratios. Monetary values should also be assigned.

After monetary values are established to satisfy mitigation issues, negotiations for an agreeable dollar amount can be achieved. The negotiated amount should cover replacement, support, maintenance, initial project costs and an ongoing monitoring program for a three year period.

Agencies involved in the mitigation process should incorporate funding in their planning process to provide ongoing maintenance to the re-established and recovering mitigated areas prior to the termination of the mitigation agreement.

Reducing impacts of brood parasitism by Brown-headed Cowbirds on riparian-nesting migratory songbirds

Sara H. Schweitzer[1], Deborah M. Finch[2], and David M. Leslie, Jr.[3]

Abstract.—Riparian habitats throughout the Southwest have been altered directly and indirectly by human activities. Many migrant songbird species specific to riparian communities during the breeding season are experiencing population declines. Conversely, the Brown-headed Cowbird (*Molothrus ater*) benefits from fragmentation of, and livestock grazing in and near riparian habitat. Brood parasitism by cowbirds may accelerate the process of local extirpation of small, remnant populations of migratory songbirds. Cowbird trapping programs have successfully reduced brood parasitism of the Least Bell's Vireo (*Vireo bellii pusillus*) and Southwestern Willow Flycatcher (*Empidonax traillii extimus*) in riparian habitats of California. This removal technique has not been used commonly in riparian habitats of other states but may be beneficial if a significant problem is identified. Preliminary surveys should be conducted to determine abundance and distribution of cowbirds, and nests of potential hosts should be monitored to assess rate of parasitism. It is not likely that remnant populations of migratory songbirds can sustain parasitism rates greater than 30%. We provide trapping, habitat restoration, and research suggestions to improve management strategies for cowbird hosts nesting in riparian zones.

INTRODUCTION

Changes in riparian habitat

The first naturalists to visit the Rio Grande Valley near Albuquerque in the 1800s found vast flocks of waterfowl and extensive marshes (Funk 1993). These ecosystems co-existed with irrigation systems for farming constructed by Native Americans and improved by Spanish colonists (Scurlock 1988; Funk 1993). These agricultural impacts were smaller spatially and changed the ecosystem more slowly than those imposed by Anglo-American settlers in the mid- to late-1800s (Scurlock 1988).

Since the late 1800s, Arizona and New Mexico lost about 90% (Johnson 1989) and California lost about 95% (Roberts et al. 1980) of their pre-Anglo-American riparian habitat. Remaining cottonwood-willow forests in Arizona and New Mexico are home to more than 100 state and federally listed threatened and endangered species (Johnson 1989).

The floodplain riparian community of New Mexico has changed significantly since settlement by Anglo-Americans (deBuys 1993; Dick-Peddie 1993). The waters of the Rio Grande are used intensively for irrigation of agricultural crops and are controlled by channels and levee systems. More than 2,833 ha (7,000 ac) of wetlands of the Middle Rio Grande ecosystem have been drained (Funk 1993). Remaining cottonwoods date back to

[1] *Assistant Professor, D.B. Warnell School of Forest Resources, University Georgia, Athens, GA.*

[2] *Project Leader and Research Wildlife Biologist, U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station, Albuquerque, NM.*

[3] *Unit Leader and Adjunct Professor, National Biological Service, Oklahoma Cooperative Fish and Wildlife Research Unit, Dept. Zoology, Oklahoma State University, Stillwater, OK.*

the flood of 1941 (Funk 1993), and cottonwood (*Populus* spp.) and willow (*Salix* spp.) regeneration is minimal. Exotic woody species such as *Tamarix* spp. (salt cedar), *Elaeagnus angustifolia* (Russian olive), and *Ulmus pumila* (Siberian elm) have become established and are expanding their distributions in the riparian community (Scurlock 1988; Funk 1993; Mount et al. [in press, this volume]). Dumping, arson, and vandalism from adjacent urban dwellers are frequent (deBuys 1993; Dick-Peddie 1993).

Impacts of changes on avian species

In the Southwest, migratory songbirds frequently select riparian habitat for nesting (Carothers et al. 1974; Ohmart 1994). Hubbard (1971) estimated that 25% of breeding avifaunas found in the Gila and San Juan river valleys of New Mexico were restricted to riparian habitat. Greater than 50% (Ohmart 1994) of avian species listed as endangered by the New Mexico Department of Game and Fish, depend on riparian and aquatic habitat for breeding and/or feeding sites. Throughout the Southwest, lowland desert riparian ecosystems support a disproportionate number of rare and endangered bird species (Johnson et al. 1987).

Loss of mature broadleaf trees (e.g., cottonwood spp.) and snags along the Colorado, Gila, Salt, and Santa Cruz Rivers of Arizona coincided with the decline of large raptors and cavity nesters (Hunter et al. 1987). In low elevation river systems, loss of broadleaf tree and shrub mixtures resulted in the decline or absence of nine neotropical migratory songbird species (Hunter et al. 1987).

Cowbird range expansion

Concomitant with loss and degradation of riparian habitat, nesting migratory songbirds have experienced increased rates of parasitism by Brown-headed Cowbirds (*Molothrus ater*). Cowbird abundance and distribution in North America have changed significantly since the arrival of Europeans. Originally, the Brown-headed Cowbird was distributed in the central short- and mixed-grass prairies of North America (Great Plains and Great Basin regions; Mayfield 1965; Rothstein 1994). The cowbird was rare in the unbroken tracts of forest in the eastern United States (Mayfield 1965). Because the Brown-headed Cowbird maintained a symbiotic relationship with large grazing animals of the prairies, especially bison (*Bison bison*), its abundance and distribution were limited by sizes of grazing herds and their migratory patterns. Cowbirds benefit from grazing animals by feeding on flushed insects and seeds exposed on bare, trampled ground (Friedmann 1929; Mayfield 1965). The tallgrass prairies and unbroken forests did not provide adequate foraging habitat for large populations of cowbirds. By the late 1700s, the eastern forests had been opened substantially by loggers and farmers. In addition, herdsmen opened pathways to the West and began to increase the number of cattle, sheep, and swine grazing and trampling the tallgrass prairie (Mayfield 1965). The cowbird expanded its range and increased in abundance in response to Europeans' creation of additional foraging habitat and to tolerant, naive hosts (Mayfield 1965; Brittingham and Temple 1983; Friedmann and Kiff 1985).

In the West around 1900, the "Nevada" or "Sagebrush" Cowbird (*M. a. artemisiae*) was widespread throughout the Great Basin and adjoining parts of Oregon and Washington east of the Cascades (Laymon 1987; Rothstein 1994). The Spaniards brought livestock into the Colorado River valley in the late 1600s and may have enabled the "Dwarf Cowbird" (*M. a. obscurus*) to become common by the early 1900s along the Colorado River, the Tucson, Arizona area, and farther east to Texas (Rothstein 1994). Cowbird abundances increased in response to improved feeding habitats provided by irrigation and agriculture (e.g., waste seed remaining in agricultural fields, increased density of livestock) in the Southwest and forest-clearing in the Sierra Nevada, Cascades, and Pacific Northwest (Rothstein 1994).

Response of host populations

Hosts susceptible to cowbird parasitism tend to exhibit one or more of the following traits: 1) build open cup nests (Friedmann 1929; Laymon 1987); 2) have an incubation period longer than that of cowbirds (Mayfield 1977); 3) are long-distance migrants (e.g., neotropical migrants) and have few opportunities to renest due to their short breeding season (May and Robinson 1985); 4) are smaller

than cowbirds (Mayfield 1965); 5) are "new" hosts that have not developed anti-parasite behavior (Mayfield 1977, May and Robinson 1985); and 6) nest in the interface between open and forested habitats (Brittingham and Temple 1983).

Cowbird parasitism has the potential to reduce recruitment rates of host species. Possible reasons for reduced reproductive success of host species include removal of host's egg(s) from the nest by the cowbird (Friedmann 1963; Weatherhead 1989; Sealy 1992; Robinson et al. 1993), a shorter incubation time for cowbird eggs (11 days) relative to eggs of most hosts (12 to 14 days) giving cowbird chicks a "head start" (Friedmann 1963, Robinson et al. 1993), larger size of cowbird chicks relative to chicks of the host increasing the cowbird chick's successful competition for food (Robinson et al. 1993), and a faster growth rate of cowbird nestlings allowing them to out-compete host nestlings for food and space in the nest (Mayfield 1977).

Hosts nesting in fragmented patches of shrubs, trees, and open prairie are likely targets of cowbirds. Cowbirds divide their activities between shrub and forest breeding habitats, and open foraging habitats such as short grass pastures, paddocks, corrals, lawns, feeders, etc. Distance between habitat types is not likely a limiting factor in site selection by cowbirds. In Rothstein's (1994) studies in California, radio-tagged cowbirds were recorded commuting up to 6.7 km from communal feeding sites to breeding territories. Cowbirds conduct breeding activities (e.g., courtship, egg-laying) in their individual territories in the morning then fly to localized, communal foraging sites in the afternoon (Rothstein et al. 1980, 1984).

Rothstein (1994) noted that brood parasitism by cowbirds is partially or mainly responsible for the decline of at least ten songbird species in California. Many of these host species are obligate riparian breeders in all or much of their range (Rothstein 1994). In the Sacramento Valley of California, Gaines (1974) found that the spread of Brown-headed Cowbirds into riparian forest resulted in the decline or disappearance of 9 species of passerines susceptible to nest parasitism. It is probable that cowbird parasitism, if left unchecked, will cause the extirpation of many remnant populations in narrow fragments of riparian habitat (Rothstein 1994). Especially vulnerable are those species with no reservoir populations that escape cowbird parasitism (Mayfield 1965). Vulnerable species may include small, long distance migrants that normally produce only one brood a year (e.g., warbler, vireos, and flycatchers; Mayfield 1977), and passerines occurring in small disjunct populations limited to patches of suitable habitat (Rothstein et al. 1987; Rothstein and Robinson 1994). Small populations are particularly at risk of extirpation from cowbird parasitism because cowbirds do not reduce parasitism rates as hosts become rare (Post and Wiley 1977; Mayfield 1978; May and Robinson 1985). Rothstein (1994) surmises that most of the cowbird hosts that have declined would have maintained self-sustaining populations if large expanses of riparian habitat had remained. The primary cause of host declines in the West seems to be habitat destruction (Rothstein 1994). If extensive riparian habitats were still widespread, hosts would likely be able to survive in the presence of cowbirds (Rothstein 1994; Rothstein and Robinson 1994). Harris (1991) stated that birds nesting in riparian habitat are especially vulnerable to cowbird parasitism because this habitat is "linear, ecotonal, often patchy, and frequently near pastures, stockyards, or agricultural fields;" the preferred habitat of cowbirds.

Reducing impacts of brood parasitism

Studies on threatened populations of riparian-nesting neotropical migrants in the West have demonstrated that cowbird control programs can successfully increase the reproductive rate of host species. For example, the Southwestern Willow Flycatcher (*Empidonax traillii extimus*) was common in lowland parts of California and sporadic in montane localities (Grinnell and Miller 1944). However, as the range of the Cowbird expanded in the 1920s and 1930s, the abundance of Southwestern Willow Flycatchers declined in central and coastal California (Unitt 1987, Harris 1991). By the mid-1980s, Harris et al. (1987) estimated that the entire California population had less than 150 pairs. Arizona Game and Fish Department reported approximately 200 flycatchers found during 1994 surveys throughout Arizona, with 119 males on territories, at least 77 males paired, and 62 pairs breeding. New Mexico Game and Fish Department (Sartor O. Williams, III [personal communication] indicated

that about 260 flycatchers detected were during New Mexico surveys in 1994, with 116 males on territories, of which at least 95 were paired. The Southwestern Willow Flycatcher may be extirpated from Nevada and Utah (Unitt 1987). Brown (1988) and Rothstein (1994) implicated both cowbird parasitism and habitat destruction as causes of population declines of the Southwestern Willow Flycatcher.

Brown (1988, 1994) found that Southwestern Willow Flycatchers experienced a high rate of cowbird parasitism (at least 50%) along the Colorado River in Grand Canyon, Arizona and that parasitism was partially responsible for a decline in flycatcher abundance. Harris' (1991) studies along the south fork of the Kern River in Kern County, California found that 68% of nests examined were parasitized. Sedgwick and Knopf (1988) monitored Willow Flycatcher nests in northcentral Colorado (Arapaho National Wildlife Refuge) and found that Brown-headed Cowbirds parasitized 41% of nests examined. Brood parasitism was the leading cause of nest failure during Harris' study, and he suggested that brood parasitism may be the most important limiting factor to Willow Flycatchers nesting in low-elevation riparian habitats (Harris 1991). The best long-term management strategy for Southwestern Willow Flycatchers may be to reduce fragmentation of their nesting habitat and to reduce the quality of cowbird feeding sites (e.g., increase grass height and foliar cover, reduce availability of waste grain, etc.; Harris 1991).

Cowbird control programs may not be cost-effective in areas with low cowbird populations and negligible nest parasitism rates. Cowbird populations in New Mexico are reported to be lower than in Arizona and California according to the Breeding Bird Survey (Finch et al. 1995), although parasitism rates at nests of Southwestern Willow Flycatcher in New Mexico have not been determined. Spot survey and cowbird trapping programs may be needed in specific localities where cowbird and host populations are reported, even though state or regional populations of cowbirds are low. In some areas, immediate action may be required if cowbird parasitism is significantly affecting hosts' annual rate of recruitment. Whitfield (1995) began a cowbird control program along the south fork of the Kern River in Kern County, California in 1992. She found that trapping female cowbirds significantly reduced rates of parasitism and increased fledging rates of flycatchers. Controlling cowbirds by shooting, addling eggs, and removing chicks from nests did not significantly increase nest success of Willow Flycatchers. Whitfield (1995) recommends removing female cowbirds from the nesting habitat of Willow Flycatchers to reduce rates of parasitism.

The decline of the Least Bell's Vireo (*Vireo bellii pusillus*) occurred within 20 to 30 years of the population expansion of cowbirds in California (Rothstein 1994). Studies of remnant populations of vireos in the late 1970s found parasitism rates of about 50% (Goldwasser et al. 1980, Franzreb 1989). Modeling by Laymon (1987) estimated that parasitism rates greater than 48% would lead to extinction in a "short time" and parasitism rates greater than 30% would lead to an unstable population that could suffer extinction due to stochastic events. In addition to the impact of parasitism, the Least Bell's Vireo has been affected by habitat loss. The Central Valley of California lost 95% of its riparian vegetation in the 1900s, and habitat loss in southern California has been great also (Rothstein 1994).

A cowbird trapping program began operating in 1983 on Marine Corps Base Pendleton, California to increase the reproductive success rate of Least Bell's Vireos (Griffith and Griffith 1993). This program reduced the parasitism rate from more than 47% in 1981 and 1982 to 17% in 1987. There has been 0% parasitism of vireo nests since 1990. The number of singing males has increased from fewer than 20 in 1980 to 250 in 1993. Populations of the California Gnatcatcher (*Polioptila californica californica*) and Southwestern Willow Flycatcher have also increased since trapping began.

MANAGEMENT RECOMMENDATIONS

Cowbird trapping

Results of these studies on Southwestern Willow Flycatcher and Least Bell's Vireo populations demonstrate that cowbird trapping and removal programs can reduce rates of brood parasitism significantly. Suggestions for initiating a cowbird trapping and removal program to reduce brood parasitism rates on rare, riparian-nesting bird species are provided in Table 1. Data on cowbird abundance, distribution, and rates of parasitism

will indicate the extent to which the reproductive success of rare avian species is affected. The magnitude of the cowbird management program should be based on these results (Robinson et al. 1993). Data from Item 3 in Table 1 can be used to estimate the effect of the program on cowbird and host abundances, and parasitism rates. Rothstein et al. (1987) suggest that removal of females is especially critical to reducing the local breeding population of cowbirds. Although control measures described in Item 4, Table 1 were not effective in Whitfield's (1995) study in Kern County, California, Rothstein et al. (1987) recommend shooting at feeding sites that receive small numbers of cowbirds because shooting individuals is more efficient than operating traps. Layman (1987) suggests that shooting individual cowbirds in narrow, riparian habitats may be more effective than trapping.

Rothstein et al. (1987) provide recommendations for cowbird trapping programs in situations where there are abundant, dispersed feeding sites for cowbirds within a 7-km radius of host breeding sites (Table 2) and these can be used to supplement recommendations given in Table 1. Feeding sites used by cowbirds may include herds of large grazing animals, corrals, pack stations, powerline rights-of-way, lawns, bird feeders, and campgrounds. Traps have also been used successfully in breeding territories of host species (Beezley and Rieger 1987; Robinson et al. 1993; Whitfield 1995). In these situations, Robinson et al. (1993) recommend that traps be placed in open areas, near the perimeter of hosts' nesting territories, and near cowbird perch sites but not placed such that cowbirds in traps can see perch sites through the trap opening. Methods for constructing cowbird traps are given in Table 3.

The distribution and abundance of female cowbirds may be used as indices of spatial distribution and intensity of brood parasitism at the community level (Robinson et al. 1993). Because cowbirds respond and are attracted to a recording of the female chatter call, the call can be used to improve estimates of numbers of females, which tend to be harder to detect than males, and to attract individuals for removal (Rothstein et al. 1987; Robinson et al. 1993). Table 4 describes methods for counting cowbirds.

Habitat restoration

Damage to riparian ecosystems is the ultimate factor affecting the balance between avian hosts and parasites and their abundance and distribution. Long range plans of natural resource managers should strive to enhance riparian ecosystem functions. Laymon (1987) states that "reforestation is the method that holds the most promise for long-term management of cowbird parasitism." Addressing the ultimate problem of the ecosystem will involve changing land-use practices to reduce the quality and quantity of cowbird feeding areas (Robinson et al. 1993) and to increase the value of the habitat for nesting host species.

Most restoration research projects in southwestern riparian habitats have been conducted in the lower Colorado River Valley of California and

Table 1.—Suggestions for initiating a cowbird trapping and removal program.

1. Identify area(s) for cowbirds and nest surveys and studies based on known presence of individuals/populations of target host species, i.e., species of concern that are susceptible to cowbird populations.
2. Conduct initial cowbird host surveys[1] to identify cowbird feeding sites and to estimate cowbird and host abundance (Verner and Ritter 1983, Beezley and Rieger 1987, Rothstein et al. 1987, Whitfield 1995).
3. Conduct nest surveys of target host species and monitor host nests to estimate rates and reproductive success.
4. Based on survey information, determine if a cowbird trapping and removal program is needed. If so, implement the program following suggestions provided in text and tables.
5. Continue host and cowbird population surveys and nest monitoring through the duration of the cowbird control program to evaluate program success. Success can be measured by increased in host populations, recruitment rates, or nesting success, and reductions in rates of cowbird parasitism or cowbird populations. Continue program based on its effectiveness in recovering host populations. Discontinue program if the host population is recovered and cowbird parasitism is no longer judged to be a problem.
6. In areas where cowbird abundances are low but a trapping program is still necessary to recover host populations, shooting individual cowbirds, addling cowbird eggs by shaking them, and removing cowbird chicks may be effective.

[1] See Table 4 for point count method suggestions.

Table 2.—Recommendations for cowbird trapping programs where there are abundant, dispersed feeding sites for cowbirds within a 7-km radius of host breeding sites (Beezley and Rieger 1987, Rothstein et al. 1987).

1. Place traps at each possible feeding site, especially near concentrations of livestock.
2. Continue trapping program for 3 to 4 months (late March to July).
3. Continue trapping program for several years.

Table 3.—Cowbird trap design, operation, and placement.[1]

Design

1. Size of trap may range from 2 x 2.5 x 1.5 m to 5 x 5 x 2 m.
2. Traps can be constructed into panels for quick assembly and disassembly when moving them from one location to another.
3. A funnel or slit entry is located at the top of the trap. The funnel entry is dropped from the ceiling of the cage such that cowbirds circling around the sides and top of the trap have enough room to circle around the funnel and above its entrance or opening. The funnel should have some wire mesh across it and below its top wide enough for cowbirds to pass through but not presenting an obvious open hole when viewed from the floor of the cage. A slit should be wide enough for birds to enter (drop through with closed wings) but narrow enough that the birds can not exit with open wings (about 1.5" width).
4. Traps should have a small side-box with a removable side opening into it at a top corner wall no more than an arm's length in depth. Cowbirds can be collected in this side-box and easily removed.
5. Materials typically used to construct traps include:
   a. 1" x 1" chicken wire or ½" hardware cloth. Wire mesh that is 1" x 1.5" is large enough for some female cowbirds to escape, especially Dwarf Cowbirds.
   b. 2" x 2" boards for panels.
   c. Bolts and butterfly nuts with which to assemble panels.
   d. Traps may be constructed using metal or PVC to make them last longer.
6. Use the following to attract free-ranging cowbirds to the trap:
   a. live cowbirds (8 females and 5 males) as decoys,
   b. food (wheat, millet, cracked corn, or sunflower seeds), and
   c. water.
7. Managers in Texas and California have found that concentrations of cattle or other large ungulates adjacent to traps attract cowbirds to the site.

Operation

1. Place food directly under the funnel or slit entrance. Don't place food in large piles that look abnormal to cowbirds.
2. Place water dishes and perches on the sides of the trap but not where the entrance will be directly visible from them.
3. Keep the trap floor bare; remove herbaceous and woody vegetation.
4. The wings of the decoy birds can be clipped to reduce the probability of the birds' escape; however, don't clip the wings so much that they appear injured.
5. Replace decoy birds with fresh decoys each week.
6. Check traps daily and remove newly captured birds.

Placement

1. Place traps in partly open settings, near observation perches of cowbirds, but don't place traps directly under perch sites.
2. Place traps in foraging habitat especially where high concentrations of cowbirds gather. If cowbirds are widely dispersed in their foraging habitat, place the trap between the nesting habitat of their hosts and the foraging habitat.
3. If cowbirds tend to use a corridor to migrate from breeding habitat to foraging habitat due to the topography of the area (e.g., draws, hollows, saddles), place trap between habitats in the corridor.
4. The number of traps placed and the distance between them will depend on the dispersion of nesting hosts and foraging sites for cowbirds. For example, Rothstein et al. (1984) found that cowbird may travel up to 7 km between nesting and foraging sites. Thus, traps may be placed as far as 7 km apart. In Michigan, however, birds are concentrated in a smaller area and traps have been placed about every 1 km^2.

[1] *See also Robinson et al. 1993.*

Table 4.—Suggested methods for counting cowbirds and their hosts.[1]

Counting Cowbirds at communal foraging sites

1. Count by sex and age, number of cowbirds from a fixed point at feeding sites. Fixed point should be placed such that entire flock of cowbirds can be seen using binoculars. If birds are too dispersed to count from one point, add point(s) such that all birds are counted. However, fixed points should be placed far enough apart to minimize the probability of double-counting birds.
2. Do not count any birds that are not positively identified as cowbirds.
3. Count at feeding sites during the afternoon (>12-noon).
4. Counts should last from 5 to 10 min.; determine the maximum amount of time needed to count all birds from a fixed point then use that time as your standard throughout all surveys.
5. Counts should begin in May (when birds migrate to their breeding range and begin to establish territories) and continue through July.

Counting Cowbirds at breeding/nesting territories

1. Establish fixed points through nesting habitat of species of concern (e.g., Least Bell's Vireo; Southwestern Willow Flycatcher).
2. Place points far enough apart to avoid double-counting birds (by sight and/or song). Distance between points will differ according to habitat type (e.g., little visual obstruction vs. dense brush and trees).
3. Count for 5 to 10 min. (standardized time used for counting).
4. Conduct counts in the morning (<12-noon).

[1]*See also Whitfield 1995.*

Arizona. Anderson et al. (1979) began a project there in 1977 in the Valley and found that they could increase horizontal and vertical height diversities of the riparian vegetation by replacing salt cedar monocultures with native cottonwood, willow, honey mesquite (*Prosopis glandulosa*), quail bush (*Atriplex lentiformis*), and annual forbs. Numbers and densities of bird species were enhanced by the restoration experiment. Additional restoration work and monitoring of wildlife population parameters has continued in the lower Colorado River Valley (California and Arizona) and along the Kern River (California) (Anderson and Ohmart 1980, 1984; Anderson 1989; Anderson and Laymon 1989; Anderson et al. 1989; Hunter et al. 1989). In New Mexico, Swenson and Mullins (1985) and Swenson (1988) successfully reestablished native cottonwood and willow in degraded riparian habitat along the middle Rio Grande.

RESEARCH SUGGESTIONS

Most cowbird-host relationship studies, and riparian restoration and subsequent monitoring of responses of flora and fauna in the Southwest have occurred in California and Arizona. There has been little research or management conducted in riparian ecosystems of New Mexico. To determine the effects of habitat restoration efforts and cowbird management programs on sensitive migratory songbirds, surveys that document species abundance and distribution must continue. Nests of endangered and rare species must be monitored to determine rates of brood parasitism by cowbirds. These results will provide essential data for determining species richness, evenness, and diversity relative to habitat conditions, and for calculating reproductive success of hosts relative to habitat and cowbird management. Evaluation of factors such as size of habitat blocks, extent of edge, and habitat isolation on host nest placement and vulnerability to cowbird parasitism are likely to be useful in developing models for managing and restoring riparian landscapes. In addition, these data can be compared to land-use practices such as grazing and agriculture in and near the riparian habitat. These data are necessary to evaluate our ability to reduce the ultimate and proximate factors adversely affecting riparian-nesting migratory songbird populations and to enhance overall condition of riparian ecosystems.

ACKNOWLEDGMENTS

We thank Wang Yong and Sartor Williams III for reviewing the manuscript and Joyce Patterson for her assistance with poster presentation. Fund-

ing for this paper was provided through Cooperative Agreement 28-C4-853 between Oklahoma State University and the Albuquerque Laboratory of the Rocky Mountain Forest and Range Experiment Station.

REFERENCES

Anderson, B.W. 1989. Research as an integral part of revegetation projects. In: D.L. Abell, technical coordinator. Proc. California riparian system conference: protection, management, and restoration for the 1990s. USDA Forest Service, Gen. Tech. Rep. PSW-110. 413-419 pp.

Anderson, B. W.; Ohmart, R.D.; Disano, J. 1979. Revegetating the riparian floodplain for wildlife. Pp. 318-331 In: R.R. Johnson, and J.F. McCormick, technical coordinators. Proc. Symp. Strategies for Protection and Management of Floodplain Wetlands and other Riparian Ecosystems. USDA Forest Service, Gen. Tech. Rep. WO-12.

Anderson, B.W.; Ohmart, R.D. 1980. Designing and developing a predictive model and testing a revegetated riparian community for southwestern birds. Pp. 434-450 In: R. M. DeGraff, technical coordinator. Proc. Workshop Management of Western Forest and Grassland Nongame Birds. USDA For. Serv., Gen. Tech. Rep. INT-86.

Anderson, B. W., and R. D. Ohmart. 1984. Avian use of revegetated riparian zones. Pp. 626-631 In: R. E. Warner and K. M. Hendrix, editors. California riparian systems: ecology, conservation, and productive management. Univ. Calif. Press, Los Angeles.

Anderson, B. W., and S. A. Laymon. 1989. Creating habitat for the Yellow-billed Cuckoo (*Coccyzus americana*). Pp. 468-472 In: D. L. Abell, technical coordinator. Proc. California riparian system conference: protection, management, and restoration for the 1990s. USDA For. Serv., Gen. Tech. Rep. PSW-110.

Anderson, B. W., W. C. Hunter, and R. D. Ohmart. 1989. Status changes of bird species using revegetated riparian habitats on the lower Colorado River from 1977 to 1984. Pp. 325-331 In: D. L. Abell, technical coordinator. Proc. California riparian system conference: protection, management, and restoration for the 1990s. USDA For. Serv., Gen. Tech. Rep. PSW-110.

Beezley, J. A., and J. P. Rieger. 1987. Least Bell's Vireo management by cowbird trapping. Western Birds 18:55-61.

Brittingham, M. C., and S. A. Temple. 1983. Have cowbirds caused forest songbirds to decline? BioScience 33:31-35.

Brown, B. T. 1988. Breeding ecology of a Willow Flycatcher population in Grand Canyon, Arizona. Western Birds 19:25-33.

Brown, B. T. 1994. Rates of brood parasitism by Brown-headed Cowbirds on riparian passerines in Arizona. J. Field Ornithol. 65:160-168.

Carothers, S. W., R. R. Johnson, and S. W. Aitchinson. 1974. Population structure and social organization of southwestern riparian birds. Am. Zool. 14:97-108.

deBuys, W. 1993. Moving from diverse viewpoints to results. Pp. 255-260 In: B. Tellman, H. J. Cortner, M. G. Wallace, L. F. DeBano, R. H. Hamre, technical coordinators. Riparian management: common threads and shared interests. USDA For. Serv., Gen. Tech. Rep. RM-226.

Dick-Peddie, W. A. 1993. Riparian vegetation. New Mexico vegetation: past, present, and future. Univ. New Mexico Press, Albuquerque.

Franzreb, K. E. 1989. Ecology and conservation of the endangered Least Bell's Vireo. U.S. Fish Wildl. Serv., Biol. Rep. 89(1).

Friedmann, H. 1929. The cowbirds: a study in the biology of social parasitism. Charles C. Thomas Publisher, Springfield, IL.

Friedmann, H. 1963. Host relations of the parasitic cowbirds. National Museum Bull. 233, Smithsonian Inst., Washington, D.C.

Friedmann, H., and L. F. Kiff. 1985. The parasitic cowbirds and their hosts. Proc. Western Found. Vert. Zool. 2:227-302.

Funk, R. 1993. Rio Grande Valley State Park. Pp. 159-161 In: B. Tellman, H. J. Cortner, M. G. Wallace, L. F. DeBano, R. H. Hamre, technical coordinators. Riparian management: common threads and shared interests. USDA For. Serv., Gen. Tech. Rep. RM-226.

Gaines, D. 1974. A new look at the nesting riparian avifauna of the Sacramento Valley, California. Western Birds 5:61-80.

Goldwasser, S., D. Gaines, and S. R. Wilbur. 1980. The Least Bell's Vireo in California: a de facto endangered species. Am. Birds 34:742-745.

Griffith, J. T., and J. C. Griffith. 1993. Brown-headed Cowbird trapping and Least Bell's Vireo

recovery on Marine Corps Base Camp Pendleton, 1983-1993. P. 30 In: T. Cook, editor. Abstracts of the North American research workshop on the ecology and management of cowbirds. Austin, TX.

Grinnell, J., and A. H. Miller. 1944. The distribution of the birds of California. Pac. Coast Avifauna No. 27.

Harris, J. H. 1991. Effects of brood parasitism by Brown-headed Cowbirds on Willow Flycatcher nesting success along the Kern River, California. Western Birds 22:13-26.

Harris, J. H., S. D. Sanders, and M. A. Flett. 1987. Willow Flycatcher surveys in the Sierra Nevada. Western Birds 18:27-36.

Hubbard, J. P. 1971. The summer birds of the Gila Valley, New Mexico. Nemouria 2:1-35.

Hunter, W. C., R. D. Ohmart, and B. W. Anderson. 1987. Status of breeding riparian-obligate birds in southwestern riverine systems. Western Birds 18:10-18.

Hunter, W. C., B. W. Anderson, and R. E. Tollefson. 1989. Bird use of natural and recently revegetated cottonwood-willow habitats on the Kern River. Pp. 332-338 In: D. L. Abell, technical coordinator. Proc. California riparian system conference: protection, management, and restoration for the 1990s. USDA For. Serv., Gen. Tech. Rep. PSW-110.

Johnson, A. S. 1989. The thin green line: riparian corridors and endangered species in Arizona and New Mexico. Pp. 35-46 In: G. Mackintosh, editor. In defense of wildlife: preserving communities and corridors.

Johnson, R. R., L. T. Haight, and J. M. Simpson. 1987. Endangered habitats versus endangered species: a management challenge. Western Birds 18:89-96.

Laymon, S. A. 1987. Brown-headed Cowbirds in California: historical perspectives and management opportunities in riparian habitats. Western Birds 18:63-70.

May, R. M., and S. K. Robinson. 1985. Population dynamics of avian brood parasitism. Am. Naturalist 126:475-494.

Mayfield, H. F. 1965. The Brown-headed Cowbird, with old and new hosts. Living Bird 4:13-28.

Mayfield, H. F. 1977. Brown-headed Cowbird: agent of extermination? Am. Birds 31:107-113.

Mayfield, H. F. 1978. Brood parasitism reducing interactions between Kirtland's Warblers and Brown-headed Cowbirds. Pp. 85-91 In: S. A. Temple, editor. Endangered birds: management techniques for preserving threatened species. Proc. Symp. Manage. Tech. for Preserving Endangered Birds. Univ. Wisconsin Press.

New Mexico Department of Game and Fish. 1988. Handbook of species endangered in New Mexico. Santa Fe.

Ohmart, R. D. 1994. The effects of human-induced changes on the avifauna of western riparian habitats. Pp. 273-285 In: J. R. Jehl, Jr. and N. K. Johnson, editors. A century of avifaunal change in western North America. Stud. Avian Biol. No. 15.

Post, W., and J. W. Wiley. 1977. Reproductive interactions of the Shiny Cowbird and the Yellow-shouldered Blackbird. Condor 79:176-184.

Robinson, S. K., J. A. Grzybowski, S. I. Rothstein, M. C. Brittingham, L. J. Petit, and F. R. Thompson. 1993. Management implications of cowbird parasitism on neotropical migrant songbirds. Pp. 93-102 In: D.M. Finch and P.W. Stangel, eds. Status and management of neotropical migratory birds. USDA For. Serv., Gen. Tech. Rep. RM-229.

Rothstein, S. I. 1994. The cowbird's invasion of the far west: history, causes and consequences experienced by host species. Pp. 301-315 In: J. R. Jehl, Jr. and N. K. Johnson, editors. A century of avifaunal change in western North America. Stud. Avian Biol. No. 15.

Rothstein, S. I., J. Verner, and E. Stevens. 1980. Range expansion and diurnal changes in dispersion of the Brown-headed Cowbird in the Sierra Nevada. Auk 97:253-267.

Rothstein, S. I., J. Verner, and E. Stevens. 1984. Radio-tracking confirms a unique diurnal pattern of spatial occurrence in the parasitic Brown-headed Cowbird. Ecology 65:77-88.

Rothstein, S. I., J. Verner, E. Stevens, and L. V. Ritter. 1987. Behavioral changes among sex and age classes of the Brown-headed Cowbird and their relation to the efficacy of a control program. Wilson Bull. 99:322-327.

Rothstein, S. I., and S. K. Robinson. 1994. Conservation and coevolutionary implications of brood parasitism by cowbirds. Trends in Ecol. and Evolution 9:162-164.

Scurlock, D. 1988. The Rio Grande Bosque: ever changing. New Mexico Hist. Review 63:131-140.

Sealy, S. G. 1992. Removal of Yellow Warbler eggs in association with cowbird parasitism. Condor 94:40-54.

Sedgwick, J. A., and F. L. Knopf. 1988. A high incidence of Brown-headed Cowbird parasitism of Willow Flycatchers. Condor 90:253-256.

Swenson, E. A., and C. L. Mullins. 1985. Revegetating riparian trees in southwestern floodplains. Pp. 135-143 In: R. R. Johnson, C. D. Ziebell, D. R. Patten, P. F. Folliott, and R. H. Hamre, technical coordinators. Riparian ecosystems and their management: reconciling conflicting uses. USDA For. Serv., Gen. Tech. Rep. RM-120.

Swenson, E. A. 1988. Progress in the understanding of how to reestablish native riparian plants in New Mexico. Pp. 144-150 In: K. M. Mutz, D. J. Cooper, M. S. Scott, and L. K. Miller, technical coordinators. Proc. symp. restoration, creation, and management of wetland and riparian ecosystems in the American West. Rocky Mountain Chapter of the Society of Wetland Scientists. PIC Technologies, Inc. and CRS Sirrine, Inc.

Unitt, P. 1987. *Empidonax traillii extimus*: an endangered subspecies. Western Birds 18:137-162.

Weatherhead, P. J. 1989. Sex ratios, host-specific reproductive success, and impact of Brown-headed Cowbirds. Auk 106:358-366.

Whitfield, M. J. 1995. Results of a Brown-headed Cowbird control program for the Southwestern Willow Flycatcher. In: T. Cook, S. Sealy, S. Robinson, S. Rothstein, and J. Smith, editors. The ecology and management of cowbirds. Univ. Texas Press, Austin (*in press*).

The riparian species recovery plan: A status report

Steven M. Chambers[1]

Abstract.—Several Federal and State agencies in Arizona and New Mexico are collaborating on the development of a strategy for the restoration of riparian systems. The strategy that is taking shape is the development of a package of formats, methods, and information that can guide local groups in developing and implementing local riparian restoration plans. The major elements of the preliminary strategy are described.

INTRODUCTION

The proposed listing of the southwestern willow flycatcher (*Empidonax traillii extimus*) as an endangered species (USFWS 1993) had implications and repercussions that may seem out of proportion to proposed protection of a single bird subspecies. The flycatcher is a riparian-dependent species found primarily in Arizona, New Mexico, and California, with peripheral populations in some neighboring states. The proposed listing of a relatively widespread, riparian-dependent species was of great concern to Federal and State agencies that for several years had been carrying out riparian enhancement programs and recovery actions for previously listed endangered and threatened species. If the flycatcher could be proposed for protection, what additional riparian-dependent species may eventually need Endangered Species Act (ESA) protections?

Federal agencies in Arizona and New Mexico responded by exploring how they could accelerate the restoration of riparian habitats to achieve recovery of listed species and obviate the need to list additional species. It was immediately recognized that successful implementation would require the participation of private interests and should not stop at the boundaries of federal lands. Participation of state game and fish agencies was also seen as essential. With the encouragement of the Southwestern Region of the USDA Forest Service and the Arizona and New Mexico State Offices of the Bureau of Land Management, the U.S. Fish and Wildlife Service appointed a Riparian Species Recovery Team to develop a comprehensive recovery strategy, or Riparian Species Recovery Plan, for riparian-dependent species through the restoration of riparian systems. The following team members were appointed to represent their respective agencies in the development of the plan: Douglas W. Shaw (Forest Service), Andy Dimas (New Mexico State Office of the BLM), Ron Hooper (Arizona State Office of the BLM), Michael Hatch (New Mexico Department of Game and Fish), and Lawrence M. Riley (Arizona Game and Fish Department). The author is serving as the U.S. Fish and Wildlife Service's liaison to the Team.

Development of the strategy by the team is still in progress. This paper is a preliminary report on the possible content of the strategy and describes some of the major elements that are now being considered for inclusion in the strategy. This list of elements should be considered preliminary and subject to deletions, additions, or changes in emphasis as the Team continues its work.

TEAM MISSION STATEMENT

In their earliest deliberations, the Team developed the following mission statement to guide their development of a riparian strategy.

[1] *Supervisory Fish and Wildlife Biologist, Division of Endangered Species, U.S. Fish and Wildlife Service, P.O. Box 1306, Albuquerque, NM 87103.*

Mission: Provide guidance and coordination to help restore ecological processes and native biodiversity for the recovery of sustainable riparian ecosystems and thereby:

- Build commitment and support from stakeholders for the protection of threatened and endangered species.
- Relieve regulatory requirements associated with the protection of threatened and endangered species.
- Obviate the need to list riparian-dependent species in the future.
- Promote socioeconomic health and sustainable use and enjoyment.

This mission will be accomplished through development of a strategy that will:

- Identify flexible, creative options under Endangered Species Act that may relieve regulatory requirements.
- Provide a framework for action that will promote synergy between diverse public and private efforts towards the common goal of riparian restoration.
- Provide tools for assessment and analysis of riparian conditions, implementation of recovery actions, and for periodic &/or continuous evaluation of the outcome of recovery actions.
- Foster commitment on the part of agencies, individuals, and private groups toward restoration activities.
- Improve communication to narrow the perceived gap between public and private sector interests, and to develop cooperation towards a common vision of riparian health.

ELEMENTS OF THE STRATEGY

1. Summary assessment of riparian in the Southwest

This preliminary section will describe in general terms the basis and need for a strategy to cover riparian systems. Prominent features would be the history of use of riparian areas, and the special features of Southwestern riparian that need to be considered, such as the complex pattern of habitats in any riparian system and the dynamic nature of these systems. These features make it impossible to formulate a single standard for riparian habitat conditions and provide management prescriptions to achieve it. These complexities can only be addressed at local planning units, where history and the dynamics of these systems can be assessed in the context of current land use.

2. Public-driven approach

The participating agencies immediately recognized that riparian restoration and recovery cannot be achieved only within the boundaries of agency lands. Because the processes that determine the health of riparian habitats do not cease to operate at administrative boundaries, restoration efforts must occur with participation of the affected public. The level of participation will always be significant, but will also depend on the extent of private lands in a planning area. Areas with primarily private lands will require private leadership of the effort, and not simple participation.

Some may question the willingness of private groups to lead a process to benefit endangered and threatened species in the current, anti-regulatory environment. The basis for the Team's optimism is the expectation that many riparian users, if their concerns about regulation and property rights can be set aside, have a vision of riparian quality that is consistent with recovery of riparian habitat. Restoration of riparian health can also have economic benefits to users. In addition, a comprehensive management plan can simplify regulatory compliance and review; in the place of multiple users applying individually and project-by-project for permits or clearances to carry out actions, a single, comprehensive plan can undergo a single review that will cover all foreseeable actions within the planning area.

Although incentives may exist for developing such plans, the knowledge on how do so may not be available. The strategy will identify sources of information, such as Bolling's (1994) book, *How to Save a River*, to help local groups initiate and gains support for a local riparian plan. Many of the following sections of the plan will provide additional access to tools for the development of a local riparian plan.

3.Format for a local assessment

The strategy will include a standard format to guide local groups in their assessment of the current status of the planning area and the objectives of their plan. The objective of this assessment is to give the group direction on how to efficiently achieve their ends by identifying essential information needs. Because the format is intended to facilitate, and not to regulate, the development of local plans, it will also have sufficient flexibility to allow special conditions of a given planning area to be considered. The objective in proposing a standard but flexible format is to promote consistency from plan-to-plan, while allowing modifications to fit local conditions.

4. Higer-level assessments

The size of local planning units will depend on a variety of conditions, including common uses, resources, and interest. A higher-level assessment, at a sub-basin or basin level, could be important in coordinating the local plans and ensuring their compatibility within the basin. Higher-level assessments would be primarily the responsibility of governmental agencies. Because they will require the commitment of fiscal resources, these assessments for all areas are unlikely to be done immediately for all areas. The lack of a higher-level assessment should not be seen as a barrier to immediate action, and local efforts should be encouraged to commence even without a formal higher-level assessment.

5. Resource planning procedures

The strategy will only briefly outline a sample procedure for developing, implementing, and evaluating local plans. Detailed planning processes have already been developed by agencies for their own use and can be easily adapted by local planning groups. Sources of detailed guidance to planning, such as the USDA Forest Service's (1993) Integrated Resource Management, will be referenced along with a source for local groups to obtain copies.

6. Riparian assessment and monitoring techniques

The strategy document will give an abbreviated outline or checklist of techniques and sources of assessment and monitoring techniques. For example, BLM's Riparian Areas Management: Process for Assessing Proper Function Condition (Prichard et al. 1993) is a good general guide to these techniques that can be recommended in the strategy.

7. Riparian management techniques

This section would be in the form of an annotated list of proven management techniques, and would include references to sources of information and technical assistance.

8. Simplifying compliance with regulatory standards

A major incentive for participating in a local plan is to greatly simplify and reduce the burden of regulatory requirements. This section will review the regulatory standards, such as for the Endangered Species Act and Clean Water Act, and provide advice on how the plan can be designed to satisfy regulatory requirements and avoid the need for further permits and regulatory reviews. Information would also be provided on the ranges and general habitat needs of species that may need to be addressed in the local plan.

9. Conservation agreements

This section would provide format and guidance on developing cooperative conservation agreements, which are useful in documenting how parties, both private and governmental, will cooperate in implementing the local plan. These agreements can also form the basis of gaining regulatory clearance of actions under the plan.

10. Sources of funding and technical assistance

Although most funding may be locally generated, possible sources of governmental and foundation grant support will be listed. Additional lists will provide sources of technical services that agencies may be willing to provide as their in-kind contribution to the local plan. A checklist of types of bibliographical information that would be of value, such as Environmental Impact Statements

prepared for earlier projects in the area, could also be included. Existing compilations of sources, such as the *Riparian/Wetland Research Expertise Directory* (Tellman and Jemison 1995) will also be cited.

11. Other local planning efforts

Local groups will find it helpful to contact other groups involved in similar plans. This section will identify ongoing efforts and contacts so that local groups can coordinate and share experiences as they develop their plans. The New Mexico Riparian Council's compendium of riparian restoration activities will be a valuable reference in this section, as will the directory compiled by Tellman and Jemison (1995).

12. Interagency agreements

Cooperating Federal and State agencies would develop and sign agreements committing themselves to the high priority of riparian management on lands that they manage. The agencies would also express the intent to provide technical assistance to the local planning efforts. This technical assistance would advise local efforts in strictly technical areas, such as hydrology or fisheries biology, and in regulatory areas so that the eventual plan will achieve both resource and regulatory objectives.

CONCLUSION

The objective of the strategy is to provide a package of information to local planning groups to encourage them to undertake riparian restoration and provide guidance for the development of their plan. The package should minimize the effort expended by planning groups on decisions about formats and in locating sources of information and assistance. In developing these materials, the Team has sought to avoid duplicating efforts by directing planners to existing formats and procedures and using checklists of possible sources whenever possible. The intent is to facilitate the planning process for local planning groups so that they can focus on actual planning and resolution of issues.

LITERATURE CITED

Bolling, D. M. 1994. How to Save a River. Island Press, Covelo, California. 300 pp.

Prichard, D., H. Barrett, J. Cagney, R. Clark, J. Fogg, K. Gebhardt, P. Hansen, B. Mitchell, and D. Tippy. 1993. Riparian Areas Management: Process for Assessing Proper Functioning Condition. TR-1737-9. Bureau of Land Management, BLM/SC/ST-93/003+1737, Service Center, CO. 60 pp.

Tellman, B., and R. Jemison. 1995. Riparian/ Wetland Research Expertise Directory. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station.

USDA Forest Service. 1993. Integrated Resource Management; The Road to Ecosystem Management, 4th Edition. USDA Forest Service, Southwestern Region, Albuquerque, NM.

U.S. Fish and Wildlife Service. 1993. Proposed rule to list the southwestern willow flycatcher as endangered with critical habitat. 58 Federal Register: 39495-39668.

Current and desired future conditions

Effects of livestock management on Southwestern riparian ecosystems

David J. Krueper[1]

Abstract.—Riparian habitats historically constituted 1% of the land mass in western North America. Within the past 100 years, an estimated 95% of this habitat has been altered, degraded or destroyed due to a wide variety of land use practices such as river channelization, clearing for agriculture, livestock grazing, water impoundments and urbanization. Many authors now concur that the single most important land management practice impacting western riparian ecosystems has been unmanaged domestic livestock grazing. Over 70% of the western United States is currently being grazed by livestock in habitats ranging from sea level to alpine meadows. Unwise grazing practices have been shown to negatively affect Southwestern riparian vegetative composition, ecosystem function, and ecosystem structure. This has resulted in negative impacts on native wildlife populations including insects, fish, reptiles, amphibians, birds, and mammals. Negative impacts due largely from over a century of heavy domestic livestock utilization in riparian ecosystems has resulted in the decline of many wildlife populations. Studies have shown that up to 70% of avian species in the desert Southwest depend upon riparian habitats for survival at some stage of their life. Over forty percent of Arizona's state-listed bird species are considered to be riparian obligate species. Ninety percent of Arizona's native fish species are now extinct, extirpated, or Federally or state listed. Many other vertebrate species have declined in recent years due to alteration of riparian habitats, and may soon be considered for Federal listing. To prevent future listings and to reverse population declines of sensitive wildlife species, land management agencies need to implement appropriate practices within riparian ecosystems.

INTRODUCTION

"...(t)hey tell a story of bare dirt, manure, eroded gullies and endless fences slicing through what once was open, wild rangeland. This story is all too familiar to those who know and love the American West. From Canada to Mexico and beyond, few arid and semi-arid landscapes west of the 100th meridian have been free of the influence of livestock, whose 'management' has contributed to loss of native vegetation, invasions by alien plants, decline of native fishes due to dewatering of streams for irrigation and degradation of riparian zones, eradication of native carnivores and prairie dogs, diseases in native herbivores, and major changes in fire frequency, hydrology, soils and other ecosystem properties. Many conservationists claim that livestock has done more damage to the native biodiversity of western North America than all the chainsaws and bulldozers combined.... Overall, agriculture - especially livestock production - has had a much greater influence on the ecosystems of western North America than development. Yet, the response of conservationists to the problem of livestock has been sluggish, perhaps because the cumulative effects of livestock grazing are much less visible to most people than clearcuts, subdivisions, or shopping malls...." (Noss 1994)

[1] *Bureau of Land Management, San Pedro Riparian National Conservation Area, 1763 Paseo San Luis, Sierra Vista, AZ, 85635.*

The American Southwest encompasses portions of 12 states within the western United States and northern Mexico, including Baja California Norte, Baja California Sur, Chihuahua, Coahuila, Sonora, Arizona, California, Colorado, Texas, New Mexico, Nevada and Utah (Rinne and Minckley 1991). The region is primarily composed of the Chihuahuan and Sonoran Deserts, with smaller portions of the Mohave and Great Basin Deserts at the western and northern boundary. Isolated mountains, plateaus, rivers and streams are dispersed throughout the region. Elevations range from below sea-level to higher than 3500 m. Yearly temperatures may vary up to 70° C between winter and summer extremes. Precipitation averages less than 5.0 cm per year in the driest portions of the Southwest, and may exceed 120 cm in the mountains. Typically evaporation exceeds precipitation by a factor of up to five times the total yearly rainfall, and surface water in streams or rivers is often present for only portions of the year (Krueper 1993). Most of the vegetative life-zones of the western United States are present, often within relatively few miles of one another along an elevational gradient of up to 2500 m. These habitats include alpine tundra, coniferous forests of ponderosa pine and Douglas fir, madrean-oak woodlands, chaparral, Chihuahuan grasslands, and Upper and Lower Sonoran Deserts. The major watersheds within the Southwest support rivers which dissect portions of this seemingly inhospitable region. The rivers include the Colorado, Gila, Little Colorado, Rio Grande, and Pecos in the United States, and the Rio Conchos, Rio Yaqui, Rio Sonora, and Rio Concepcion in northern Mexico.

Riparian habitats within this region historically tied all other vegetative life zone together within a matrix of "interconnectedness." High elevation riparian habitats of aspen, maple and alder stands grade to mid-elevation sycamore, walnut and ash, which connect with cottonwood and willow dominated riparian habitats at the lower elevations. Water from ice melt in the southern Rockies of New Mexico eventually empties into the Gulf of California through the Gila and Colorado River drainages, a journey of over 1500 km. The life blood of the Southwest is water which is readily available for use by vegetative and wildlife populations. Historically, the major rivers were the large arteries of the Southwest, while the smaller cienegas, streams and oases of lush riparian habitats were the circulatory sinews which connected the entire region. Throughout the region, periodic dry spells occur relatively frequently, impacting grasslands and deserts and stressing native plant and wildlife populations in all ecosystems. In a dry year, or after a series of drought years, riparian ecosystems buffer the effects by providing cover, food and water for native wildlife. In these lean years of thermal and water stress, the need for water is often greatest when it is least available (Wiens and Dyer 1975).

Most studies of livestock grazing influences in the western United States have concentrated on effects of grassland change and how these changes have affected game animals such as mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana*), or elk (*Cervus canadensis*). Almost totally lacking are complete, in-depth research projects which measure influences of livestock grazing on native vegetation and the resultant change on nongame vertebrate species. In addition, if these studies have been initiated, they are typically of a short-term nature, often being completed within two years or less. Long-term studies of greater than five years which measure vegetative and animal population response in the absence of livestock utilization in western riparian ecosystems are virtually lacking.

Because of competing economic, social and conservation interests, the issue of public land grazing in the West has emotionally charged proponents and opponents alike (Bock et al., 1993). Public land managers often are the targets when conservationists pit themselves against the livestock industry and vice versa. The issue of public land grazing is equally as volatile as the issues which embroil the Pacific Northwest and its remaining old growth forests. The romantic image of the cowboy on the range has been ingrained into the consciousness of generations of Americans. The tough, pioneer spirit of early Western settlers was, and still is, admired by millions of people. The cowboy was, and still is, perceived as a rugged individualist, struggling to tame a wild country and bring civilization and order to an untamed land. This mythos continues to factor into our everyday lives, and has been promulgated by influences from Hollywood to Wall Street. It is a tough image to change. And with the image of the

cowboy comes his trusted horse and domestic livestock running across the open rangelands of the West.

IMPORTANCE OF RIPARIAN HABITATS

Riparian can be simply defined as the vegetation or habitats that are associated with the presence of water, whether it is perennial, subsurface, intermittent or ephemeral in nature (Krueper 1993). The Bureau of Land Management (BLM) expands the definition to include wetlands:"Wetlands include both natural and intentionally created areas adjacent to, and influenced by, streams (whether waters are surface, subsurface, or intermittent), springs, lake shores, marshes, potholes, swamps, muskegs, lake bogs, wet meadows, and estuarine areas. Riparian areas are a form of wetland transitional between permanently saturated wetlands and upland areas."(BLM Manual 1737).

The BLM currently administers over 270 million acres of public land in 13 western states. This total surface acreage is greater than the U.S.Forest Service (USFS), the National Park Service (NPS), and the U.S. Fish and Wildlife Service (USFWS) combined. Of the 270 million acres of surface lands, 23 million acres (8.5%) are considered riparian or wetland areas. Over ninety percent of this total is within the state of Alaska. In the arid states of Arizona and New Mexico, the BLM manages over 25 million acres, of which 70,530 acres are considered riparian or wetland habitats, along 1660 miles of stream. This constitutes less than three-tenths of one percent of the total Bureau-administered lands in Arizona and New Mexico (BLM files).

The importance of western riparian areas cannot be overstated or overemphasized. Western riparian ecosystems are among the rarest habitat types in the Western Hemisphere. Of the 106 forest types identified in North America, the western cottonwood (*Populus*)-willow (*Salix*) forest association has been identified as the rarest (Dan Campbell, 1988 pers. comm.). Western riparian ecosystems are highly fragmented and discontinuous due to the nature of the topography in which they are found. Even with such a limited and discontinuous distribution, up to 80% of vertebrates use riparian habitats in the desert Southwest at some stage of their life. Over fifty percent of the nesting bird species in the American Southwest use riparian habitats as the primary habitat for breeding purposes (Johnson et al. 1977). Within the San Pedro Riparian National Conservation Area (NCA) in southeastern Arizona, 526 mammal, bird, reptile, amphibian and fish species have been recorded (Table 1). Of that total, 356 species (68%) have been found using the riparian zone within the NCA for feeding, resting, water or breeding requirements (Krueper unpub. data). A minimum of 67 species (13%) are considered to be riparian obligates. Thomas et al. (1979) attributed the high wildlife species density and diversity totals of riparian habitats to the presence of highly varied vegetative structure and what they termed "ecotonal" or edge associations. The high species diversity values recorded within the San Pedro NCA are believed to be due to the availability of water, prey items (insects), high vegetative density and diversity, and the fact that it is located at the juxtaposition between several major floral and faunal ecoregions.

Table 1. Vertebrate species totals recorded within the San Pedro Riparian National Conservation Area, Cochise Co., Arizona and associated riparian occurrence, 1995. (BLM files)

Taxa	Non-rip.[1]	Facult.[2]	Obligate[3]	Totals
Fish	0	0	13	13
Amphibians	0	5	3	8
Reptiles	16	14	7	37
Birds	149	189	39	377
Mammals	5	75	5	85
Totals	170	289	67	526

[1] *Non-riparian. Non-riparian associated. Although may be found using riparian habitats it is not required for survival.*

[2] *Facultative. Requires use of riparian habitat at some stage of its life cycle.*

[3] *Obligate. Riparian obligate species.*

There is no doubt about the value of healthy riparian ecosystems, and yet these systems have traditionally been the most heavily impacted through human over-utilization, abuse or neglect (Fleischner 1994). Carothers and Johnson (1975) candidly noted the recognized value of riparian habitats in the American Southwest, yet

"it seems incredible that man travelled along, camped and trapped on, settled in and drew water from riverine ecosystems since the beginning of history without having a better understanding of the great importance of these rivers. Historians and archaelogists have consistently pointed out the importance of rivers to civilization. We heartily agree and then use them for garbage and sewage effluent disposals, dry them up, denude them of native vegetation, turn them into canals or simply dam them. For decades, just as nongame management has been subservient to game management, other values on watersheds have been disregarded while 'water management' and salvage projects receive the principal focus. This is especially true when we review the lack of concern for maintenance of natural riparian ecosystems compared to the ever increasing concerns for supplying large metropolitan areas in the Southwest with additional water for domestic, agricultural, industrial and recreational uses."

While Carothers and Johnson are accurate in their assessment of current riparian habitat management, it must be stressed that the insidious and cumulative impacts of unmanaged livestock use in Southwestern riparian ecosystems for several hundred years has probably been the single most important factor in riparian ecosystem degradation (Wagner 1978, Ohmart 1995).

Riparian habitats historically constituted 1% of the land mass in western North America. Within the past 100 years, an estimated 95% of this habitat has been altered, degraded or destroyed due to a wide variety of land use practices such as river channelization, unmanaged livestock utilization, clearing for agriculture, water impoundments and urbanization (Krueper 1993, Fleischner 1994, Ohmart 1994). Many authors now concur that the single most important land management practice impacting western riparian ecosystems has been unmanaged domestic livestock grazing (Noss 1994).

HISTORIC RANGE MANAGEMENT IN THE SOUTHWEST

Historically, the largest ungulates found in the lower elevations of the Southwest were pronghorn, mule deer and white-tail deer (*Odocoileus virginianus*). Elk were common in the higher elevations of the southern Rocky Mountains, extending south to northern Arizona and New Mexico. Desert bighorn sheep (*Ovis canadensis*) were restricted to isolated desert mountain ranges and rarely wandered to lower elevations. Large, heavy ungulates such as bison (*Bison bison*) were not present in the grasslands of the arid Southwest. The ecosystems of the Southwest had evolved in the absence of large ungulate herds (Bock et al., 1993).

Over four hundred and fifty years ago, Fray Marco de Niza became the first Spanish explorer to cross what is now the United States/Mexico International Boundary near the headwaters of the San Pedro River in Cochise Co., Arizona. Following de Niza's glowing reports of the existence of the legendary seven golden cities of Cibola and El Dorado somewhere to the north, Francisco Vasquez de Coronado set forth with a large expedition in 1542 to locate the fictional cities. Accompanying the expedition were several hundred horses for transportation, and 5,000 sheep and 150 head of cattle to be used as food during the journey (Allen 1989a). Although the expedition was a failure and all livestock were either eaten or died from the rigors of the journey, the initial exploration and ecological exploitation of the Southwest had begun.

One hundred and fifty years passed after the unsuccessful Coronado Expedition before the first serious attempt at colonization of the interior Southwest was initiated under the leadership of Padre Eusebio Francisco Kino. In the late seventeenth century, Padre Kino initiated successful animal husbandry practices within mission settlements along the Santa Cruz River in an attempt to encourage native inhabitants to raise stock, farm agriculture and settle around the missions. In 1697, Padre Kino distributed livestock to missions along the San Pedro River, Tucson, and Nogales, and shortly thereafter cattle ranching had spread to all missions and native villages in what is now southeastern Arizona.

Within several generations, cattle ranching had become the primary economic force in the region. Livestock were primarily concentrated in the lush riparian areas of the Santa Cruz and San Pedro watersheds. Allen (1989a) stated that "the significance of the mission era to modern range management lies in the introduction of livestock to the area and the beginnings of the pastoral culture, not to any widespread impacts on the surrounding range." The precedent of livestock utilization within riparian habitats had been initiated.

Allen (1989a) estimated that 100,000 cattle were grazing the headwaters of the San Pedro River and Bavispe Rivers in southern Arizona and northeastern Sonora by 1694. Within another generation, the entire portion of inhabited southern Arizona deserts had cattle and Mexican haciendas had been established throughout the region (Hastings and Turner 1965). In the mid-eighteenth century, native peoples revolted and many of the missions and ranches were abandoned. Livestock roamed freely throughout the area until Spanish forts were established to control fierce Apache raiding parties in the early nineteenth century. Although the Mexican military presence in the region deterred Apache raiding on the re-established haciendas, periodic attacks resulted in a considerable number of feral livestock. Allen (1989a) estimated that when the San Bernardino Ranch was abandoned in the 1830s, over 100,000 head of cattle were allowed to run wild. By 1846, all of the haciendas had bowed to the pressures of Apache raiding parties and had been abandoned again.

After the conclusion of the United States/Mexico War in 1848, settlers began to stream into the region, bringing with them livestock for economic gain as they pioneered the region. After the Civil War, huge numbers of cattle were moved from rangelands in Texas to provide food for the army during the Apache Wars. The end of the Apache Wars in the 1870s signalled the beginning of an unprecedented buildup of domestic livestock in Territorial Arizona. Hastings and Turner (1965) estimated that over one and a half million cattle were present in Arizona by 1891, most of which were south of the Gila River. Ohmart (1995) corroborated these numbers and also estimated that neighboring New Mexico supported two million head of cattle at the same time.

As with all regions in the West, the vagaries of weather combine to create periods of time under which conditions of great environmental stress occur. Drought and catastrophic rainfall patterns are of regular occurrence in the Southwest, and during the later part of the late nineteenth century a natural disaster occurred that was exacerbated by decades of unmanaged livestock management:

> "Livestock, introduced to the region by ranchers, had become abundant. As the uplands desiccated, cattle concentrated near streams and rivers. But even that tactic soon failed, and 75% of all livestock in Arizona were thought to have died from thirst or starvation by 1875. Ranges were severely damaged, so erosion prevailed when a wet cycle began....deep arroyos were cut from downstream to upstream, incising valley fills so deeply that water tables were drained. Marshes and riparian plants were left high and dry, and disappeared. The erosive power was concentrated downward by high channel walls." (Rinne and Minckley 1991).

The period of drought followed by damaging rains occurred throughout the western United States. Even after this ecological disaster, cattle ranching continued to hasten the demise of the region as numbers again increased. Increased numbers of cattle and sheep placed more ecological stress on riparian ecosystems which were already severely compromised. Severe erosive flooding occurred in 1887, 1890, 1891, 1905, 1906, and 1916 (Dobyns 1981), and with each flood event, stream and river channels became more incised and riparian habitat destruction increased.

Historians and ecologists unequivocally agree that the cattle numbers present in the arid grasslands of southern Arizona at this time far exceeded the carrying capacity of the rangelands, and the inevitable result of such practices was severe degradation of the uplands and riparian habitats of the entire region. Overstocking of the range during the late nineteenth century throughout the western United States initiated accelerated erosion and downcutting of streams and rivers, thereby lowering the water table and permanently altering the hydrologic functioning of riparian ecosystems. Most Southwestern riparian ecosystems have not recovered, and many authorities believe that they will never be able to return to a condition that resembles historic condition and function. Allen (1989b) observed that even in 1936, over forty years after the disastrous drought and erosive flooding events of the late nineteenth century, Secretary of Agriculture H.A. Wallace testified to the United State's Senate that:

> "There is perhaps no darker chapter nor greater tragedy in the history of land occupancy and use in the United States than the story of the western range....(R)ange depletion (is) so nearly universal under all conditions of climate, topography, and ownership that the exceptions serve only to prove the rule."

In short, "(t)he impact of countless hooves and mouths over the years has done more to alter the

type of vegetation and landforms of the West than all the water projects, strip mines, power plants, freeways and subdivision developments combined (Fradkin 1979).

CURRENT CONDITION OF SOUTHWESTERN RIPARIAN HABITATS

Over 70% of the western United States is currently being grazed by livestock in habitats ranging from sea level to alpine meadows. Livestock grazing is the most widespread economic use of public land in the American West (Bock et al. 1993). The vast majority of the 270 million acres of public land under domestic livestock use in the interior West are managed by the BLM and the USFS. According to Fleischner (1994), 7 million head of livestock graze the 16 western states, and of the entire BLM holdings in the West, 94% is currently being grazed. The loss of biological diversity on these lands has recently sparked renewed interest by the concerned public, who questions the validity of multiple use management on a sustained basis as required by law. Horning (1994) stated that livestock grazing in the western United States has contributed directly and indirectly to the decline of over 340 species of plants and animals which are currently listed or are candidate species under the Endangered Species Act.

Riparian habitats are the most modified land type in the American West (Bock et al. 1993). Nearly all public land in the western United States is currently or has been historically grazed. Riparian systems are found throughout the region, and because of the paucity of water, palatable forage and lack of shade in adjacent habitats, riparian areas are heavily impacted by domestic livestock. Due to habitat alteration, natural riparian communities persist only as isolated remnants of what was once a vast, interconnected web of rivers, streams, marshes and vegetated washes. Horning (1994) stated that grazing is the single most important factor in the destabilization of riparian and aquatic eosystems because cattle remove the protective riparian vegetation, and break down streambanks, thus increasing silt loading, widening streams, and destabilizing the water buffering qualities during temperature extremes in winter and summer.

Over 410 million acres of public and private rangelands, constituting 21 percent of the United States outside of Alaska, are considered to be in unsatisfactory condition (Wuerthner 1993). Wuerthner (1993) also stated that according to a 1990 Environmental Protection Agency report on the rangelands of the western United States, riparian areas are in the worst condition in history, and that the principle agent for this degradation is grazing. According to a 1991 BLM document, only 0.8% of riparian habitats in Arizona and 6.0% in New Mexico are considered to be meeting riparian habitat objectives (USDI BLM document 1991). The remaining lands are either not meeting riparian habitat objectives or are considered to be in "unknown status."

The BLM initiated its Riparian-Wetland Initiative of the 1990's which set goals and national strategies to upgrade or improve the ecological condition of wetland and riparian habitats on lands the agency manages. The principle objective of the initiative is to restore to "proper functioning condition" 75% of its riparian and wetland habitats by 1997. Proper functioning condition is determined when a riparian habitat:

1. Purifies water by removing sediments and other contaminants;
2. Reduces risk of flooding and associated damage;
3. Reduces stream channel and streambank erosion;
4. Increases available water and stream flow duration by holding water in stream banks and aquifers;
5. Supports a diversity of plant and wildlife species;
6. Maintains habitat for healthy fish populations;
7. Provides water, forage, and shade for wildlife and livestock;
8. Creates recreational opportunities such as fishing, camping. picnicking and other activities.

To achieve proper functioning condition by 1997, the BLM set four major goals:

1. To restore and maintain riparian and wetland areas so that at least 75 percent are in proper functioning condition by 1997;

2. To protect riparian and wetland areas and associated uplands through proper land management and by avoiding or mitigating negative impacts;
3. To carry out a riparian and wetland information and outreach program that includes training and research to raise awareness and understanding of the importance of healthy riparian habitats; and
4. To maintain existing and form new public-private partnerships to supplement and accelerate the agency's work by drawing on the talents of volunteers and using non-Federal funding (USDI BLM document 1991).

While the goals and objectives established by the Riparian-Wetland Initiative are laudable, they are also very general and non-specific. The very definition of "proper functioning condition" is open to interpretation by a wide variety of specialists or special interest groups which often lobby for support of continued traditional and consumptive uses in the interest of short-term gain rather than for the long-term benefit of riparian-related resources. Many of the remnant riparian ecosystems in the arid Southwest, although classified as being in fair to good condition within the context of the Riparian-Wetland Initiative, are actually considered "functioning, but at risk" of total collapse under current management practices (R. Ohmart, pers. comm.)

IMPACTS OF LIVESTOCK IN SOUTHWESTERN RIPARIAN HABITATS

Wuerthner (1994) recently summed up the cumulative impacts of livestock grazing in the Western United States by claiming that "(a)griculture - both livestock production and farming - rather than being compatible with environmental protection has had a far greater impact on the western landscape than all the subdivisions, malls, highways, and urban centers combined." Noss (1994) stated that livestock management practices have "contributed to loss of native vegetation, invasions by alien plants, decline of native fishes due to... degradation of riparian zones, ..and major changes in hydrology, soils and other ecosystem properties. Many conservationists claim that livestock has done more damage to the native biodiversity of western North America than all the chainsaws and bulldozers combined. Livestock grazing on public lands is rapidly becoming one of the hottest and most polarized environmental issues in the United States."

Domestic livestock are disproportinately attracted to riparian areas. High moisture and nutritive content of riparian vegetation are critical to livestock especially during dry summer months when upland vegetation is relatively desiccated and unpalatable. Add to that the availability of open water and shade during the hottest months, and it is no wonder why domestic livestock remain in riparian habitats for much of the season. In many areas of the West, the concentration of livestock in riparian habitats is exacerbated due to steep canyons, narrow riparian corridors and limited accessibility (Dahlem 1979). The result in many western riparian areas are beaten out riparian systems which are devoid of understory vegetation which most wildlife species depend upon for survival and productivity.

Livestock grazing can alter vegetative structure and composition of riparian habitat. Ryder (1980) stated that grazing, especially by livestock and big game, frequently changes plant species composition and growth form, density of stands, vigor and seed production of plants. Grazing and browsing can alter the growth form of individual plants, making shrubs and young trees grow "bushier" by removing terminal buds and stimulating more lateral branching. While the resulting growth form may benefit some species of wildlife temporarily, continued grazing on already stressed vegetation or on vegetation which has not evolved under grazing pressure can injure or even kill shrub or tree species. Unlike grasses, many species of forbs, shrubs and trees are not adapted to continual or persistent grazing and browsing pressure during the growing season (Ryder 1980). This loss of vegetation alters the vegetative density and diversity of the community, most often shifting the community from a climax condition to an earlier successional stage. Under these conditions, wildlife species which are adapted to an older, more mature vegetative ecological state will be selected against while those species which have more general habitat requirements will be selected for.

Differences between riparian habitats in good condition and degraded condition should be extremely evident to even the untrained eye. But with over 300 years of grazing pressure within riparian areas of the lowland Southwest, healthy riparian stands are virtually non-existent. Comparisons of healthy versus degraded riparian habitats are by default a moot point. A commonly heard complaint from ranchers is that the riparian areas which they are utilizing "have always looked like this." Ecological decline from overgrazing is a slow, insidious process which causes a decline in the abundance and diversity of native riparian vegetation over several generations, and is usually not evident to even skilled observers unless exceptional care is exercised. As the native plants die off, riparian areas are typically invaded by exotic plants such as Russian Olive (*Elaeagnus angustifolia*) and saltcedar (*Tamarix chinensis*) which are significantly less productive for wildlife habitat, watershed protection and wildlife forage needs.

Western riparian habitats are extremely vulnerable to overgrazing (Rucks 1978, Platts and Nelson 1985, Platts 1991, Ryder 1980, Ohmart 1994). Unmanaged grazing practices have been shown to negatively affect Southwestern riparian vegetative composition, ecosystem function, and ecosystem structure (Platts 1991, Ohmart 1994, Horning 1994, Ohmart 1995). Effects of grazing most often depends upon the intensity, duration and location of the activity. Domestic livestock typically concentrate in riparian areas where forage, water and shade are readily available. Heavy use in sensitive riparian habitats during the growing season or in years of drought accelerates degradation of riparian systems. Cattle, like all animals, must eat to survive, and in lean years they can strip a formally productive and functioning allotment into a wasteland if stocking rates are not immediately reduced. High intensity grazing also profoundly alters breeding avifaunas from the "natural" state, generally in the direction of decreased species numbers and complexity (Wiens and Dyer 1975).

Trampling of vegetation by large ungulates or even humans can impact vegetation by removing protective cover and affecting sensitive soil components, resulting in increased exposure of soil to eroding wind and water (Stoddart et al. 1975, Chaney et al 1990). Rauzi and Smith (1973) documented decreased water infiltration rates in heavily grazed habitats versus lightly grazed habitats. Lusby (1979) reported increased runoff and sediment discharge from desert rangelands of western Colorado under conditions of livestock grazing, which eventually impacts riparian ecosystem function and condition. Kuss and Hall (1991) found that trampling of vegetation and the surface layers of sensitive soils causes significant damage to floral and soil structural components even with one passage of a human through undisturbed landscapes. The weight of a two-hundred pound human being, and its resultant impact to the floral and soil components, pales in comparison to the effect of repeated use by domestic livestock which may weigh 5 to 7 times as much as a human. Early studies which measured the recovery rates of human-induced trampled habitats estimated that "50 to several hundred years may be required for the impacted communities to recover original floristic composition and density" (Kuss and Hall 1991). Their data suggested that even limited trampling delivered at one time can be as damaging as increasing levels of use delivered over a much longer time.

IMPACTS OF LIVESTOCK ON WILDLIFE POPULATIONS

Negative impacts due largely from over a century of heavy domestic livestock utilization in arid Southwestern riparian ecosystems have resulted in the decline of insect, fish, reptile, amphibian, bird, and mammal populations. Excessive historic grazing practices have significantly altered riparian vegetative structure and density, which in turn have impacted wildlife populations (Fleischner 1994). Grazed riparian areas typically have less ground cover, a poorly developed understory and midstory, and decreased vegetative biomass when compared to similar ungrazed riparian areas. These conditions result in a paucity of available niches which a great number of wildlife species depend upon for feeding, resting and cover.

Horning (1994) estimated that livestock grazing played a significant role in the listing of 76 species of fish and wildlife, and that livestock grazing is a factor in the decline of another 270 candidate and listed fish and wildlife species. Of this total, the two most arid western states (Arizona and Ne-

vada) have the most number of species harmed by grazing (86 and 75 respectively). Eighty percent of the 346 fish and wildlife species found to be seriously impacted are riparian dependent, and unmanaged grazing has severely compromised the quality of habitat upon which they depend for survival. Based on a critical literature review and advice from wildlife experts, Horning (1994) added that "there is irrefutable evidence that abusive grazing practices have severely compromised native biological diversity by damaging ecologically vital riparian areas and fragile arid and semi-arid grassland ecosystems, in some cases irreparably."

Determining the true impacts of unmanaged livestock grazing on Southwestern riparian wildlife populations is difficult to assess because there were virtually no extensive vertebrate studies conducted before the Twentieth Century. Intensive grazing has been present in the Southwest for over 300 years. Scientists have no baseline information from which to draw significant conclusions. However, we can document historical changes within the past 100 years, and then based on the evidence, infer "what might have been" from studying recovering riparian habitats that have been excluded from livestock grazing. Integral to these studies are measurements of the resultant changes in vegetation and wildlife communities through time in the absence of domestic livestock.

Carothers and Johnson (1975) mentioned that although direct economic measures of riparian alteration are possible (economic cost and benefit ratios measured in dollars earned or lost), the "intangible" values of riparian ecosystem health are much harder to define and quantify. How can an economist measure the value of a spring morning walk within the splendor of the riparian habitat surrounding the Verde or the San Pedro Rivers? What is the value of seeing a Green Kingfisher (*Ceryle americana*) amongst the root masses and overhanging streambanks of a healthy riparian system, or the diagnostic ripples in a pond as a beaver forages near a remote mountain meadow? These are the intangible values of a healthy and functioning Southwestern riparian ecosystem, and although they are nearly impossible to measure, they must be taken into account in regard to riparian habitat management. To many public land users, loss of wildlife and associated recreational opportunities due to riparian habitat destruction or alteration is an increasingly unacceptable consequence of traditional land management practices.

Invertebrates

While very little research has been conducted on the response of aquatic invertebrates to livestock grazing, much of the available evidence shows that many invertebrate species decrease as habitat is degraded (Horning 1994). Fleischner (1994) compiled data from studies which show that domestic livestock grazing has had negative impacts to terrestrial invertebrate populations in several western states, including Arizona where grasshopper densities were 3.7 times greater on protected sites than on grazed sites. Ryder (1980) also stated that insect production can be altered under heavy grazing practices. Most studies of grazing impacts on invertebrate populations have been conducted in grasslands and not within riparian habitats, but it is obvious that with vegetative disturbance and removal of plant biomass which sustains invertebrate populations, certain taxa will be negatively affected.

Fish

Platts (1991) found that in 20 of 21 studies he reviewed, riparian habitats and fish populations were negatively impacted by livestock grazing. Unmanaged livestock practices compact soils and low-growing riparian vegetation, denude marshes and meadows, trample stream banks, and remove protective riparian vegetation from the banks of watercourses. This results in increased siltation and sedimentation, increased water temperatures, and decreased habitat quality for native fish species. Behnke and Zarn (1976) concluded that livestock grazing within Western riparian ecosystems was the major threat to improving or stabilizing degraded trout habitat.

Destruction of riparian vegetation and streambank stability results in unstable water temperatures which most fish species depend upon for egg development. Increased siltation can cover gravel spawning beds which cuts off oxygen required for proper development of eggs. In many streams where livestock grazing has been limited or eliminated, native fish species are able to more effec-

tively compete with non-native fish species. In riparian livestock exclosure studies, native fish species have been shown to increase populations by nearly 600 percent (Crispin 1981, Platts and Nelson 1985).

Fish, especially colder water species such as trout, have been shown to be good indicators of ecosystem health. However, species such as the Lahontan cutthroat trout (*Salmo clarki henshawi*), the Bonneville cutthroat trout (*Oncorhynchus clarki utah*), the Apache trout (*Oncorhynchus apache*) and the Gila trout (*Oncorhynchus gilae*) are federally listed or Candidate species. These and many other species are at risk because of habitat loss and degradation associated with livestock utilization within sensitive riparian habitats. The destruction of spawning and natal rearing habitat due to logging and livestock production in sensitive riparian areas of the upper Gila River in New Mexico and in the White Mountains of Arizona have been responsible for the declines in the latter two trout species (Rinne and Minckley 1991). Fleischner (1994) stated that fish production and standing crop biomass of salmonids increased significantly when cattle were excluded from riparian ecosystems in the Great Basin and in Colorado. To determine whether these fish species would benefit from livestock exclusion from riparian areas, measurements of biomass change and overall population response need be implemented. Costs of fencing riparian areas from livestock may be less expensive than other expensive recovery efforts.

Economic costs to recover high elevation fish species to stable levels can be staggering. For instance, recovery of the Lahontan cutthroat trout is expected to top $14 million. To enhance riparian areas for the benefit of Apache trout in Arizona will cost the USFWS up to $2 million over the next 10 years. Even while these enhancement projects are being conducted, adjacent riparian areas continue to be grazed and degraded (Horning 1994).

Mid-elevation streams from 900 to 1900 m. elevation flow through low coniferous forests, oak woodlands and portions of high elevation grasslands. These habitats support most of the remaining native fish populations in the Southwest (Rinne and Minckley 1991). However, due to the extreme riparian degradation of the 1870s and 1880s as a direct result of overstocking the range in Arizona, many native fish species were extirpated from historic habitat and have not since been able to return naturally (Rinne and Minckley 1991). These systems have not had the tremendous grazing pressures that lower elevation riparian systems have sustained, but continual degradation which accompanies livestock grazing has impacted these fish populations as well.

Low elevation riparian systems below 900 m. elevation have been heavily impacted because these systems typically are in areas with extreme temperatures and low rainfall. This creates conditions which concentrate cattle into small areas, which increases soil compaction, streambank erosion and decreases vegetative cover.

Of 41 species of freshwater fishes native to the Southwest, 10 occur only in Mexico, 9 occur only in the United States, and the remaining 22 species are shared by the two countries (Rinne and Minckley 1991). By 1989, 28 of the 41 species were officially listed as threatened, endangered or of special concern by the American Fisheries Society. Three other species not considered in the above total are now officially extinct. Ninety percent of Arizona's native fish species are now extinct, extirpated, or Federally or state listed.

As a result of diversions, mineral activity, unmanaged domestic livestock practices, and other impacts "...native fishes are being exterminated. Destruction of aquatic habitats, changes from natural to artificial conditions, and predation and competition by alien species enhanced by artificial conditions, all combine to destroy them. Many are nearing extinction, some are already gone, and neither legislation, nor determined attempts at conservation by agency, academic, or other managers have succeeded in reversing the trend. The only chance seems to lie in an emergence of public opinion that recognizes native fishes as valuable resources and demands their conservation." (Rinne and Minckley 1991). Recovery of the hundreds of species and subspecies of threatened or endangered western fish will depend upon restoration of severely degraded riparian ecosystems. One of the most effective methods is livestock exclusion or more effective livestock management which will result in the stabilization of sensitive riparian soils and vegetation.

Amphibians and Reptiles

Amphibians have also been shown to decline in population size and overall distribution as riparian habitat has been degraded. In particular, species which are candidates for listing such as the yellow and red-legged frogs, the Yavapai leopard frog, as well as numerous toad species, are known to be harmed by grazing (Jennings 1988, Toone 1991, Jennings and Hayes 1993, Martin 1993). Many Western amphibian species which are dependent on functioning riparian habitats for breeding or shelter requirements are negatively impacted by unmanaged livestock grazing as riparian streambanks break down, sedimentation increases, and erosion accelerates.

Certain reptile species, including various grassland lizards and snakes, are less abundant due to livestock caused alteration of riparian habitat (Fleischner 1994, Horning 1994). The wandering garter snake, an atypical riparian-associated reptile, is much less abundant in grazed habitats relative to adjacent ungrazed habitats (Szaro et al. 1985). Fleischner (1994) reported that in two studies in California and Arizona, lizard abundance was two times and biomass 3.7 times higher on ungrazed sites relative to grazed sites, and that abundance and diversity was higher on ungrazed sites rather than on grazed sites in 80% of the study sites measured. It is clear that, similar to impacts imposed on fish populations, continued degradation of riparian habitat will not only hinder the recovery of many listed species, but will also accelerate the decline of dozens of candidate amphibian and reptile species.

Birds

Although consisting of less than 1% of the land mass of the western United States, western riparian habitats are extremely important to neotropical migratory landbirds as well as resident species (Szaro 1980, Bock et al. 1993, Krueper 1993, Ohmart 1994). In the Southwest, riparian areas support a higher breeding diversity of birds than all other western habitats combined (Anderson and Ohmart 1977, Johnson et al. 1977, Johnson and Haight 1985). Over 60% of all neotropical migratory birds use riparian habitat in the Southwest as stopover areas during migration, and these habitats have recorded up to 10 times the number of migrants per hectare than adjacent non-riparian habitats (Stephens et al. 1977, Krueper unpub. data). Because of high rates of metabolism, birds are extremely dependent on the habitats in which they find themselves during the migratory period, and must utilize seasonally abundant resources when available (Sprunt 1975). Southwestern riparian systems provide migratory bird species rich food resources during the critical migratory period because plant growth rates and resultant vegetative biomass are very high, which allows for greater insect production (Gori 1992).

The highest non-colonial avian breeding densities in North America have been reported from southwestern riparian habitats (Johnson 1970, Carothers and Johnson 1975, Anderson and Ohmart 1984, Krueper 1993). Within the San Pedro Riparian National Conservation Area in southeastern Arizona, migration and breeding densities of 3000 individuals per 40 ha have been documented (Krueper, unpublished data). Johnson et al. (1977) reported that more than 75% (127 of 166) of southwestern bird species nest primarily in riparian habitats, and 60% (59 of 98) are neotropical migratory birds.

Bird species are differentially affected by cattle grazing in riparian areas. Bird species have been shown to respond to alterations in vegetative structure and species richness within riparian habitats (Bull and Slovlin 1982, Szaro and Jakle 1985). Other avian studies have shown a higher density and diversity of birds in ungrazed riparian habitats compared to adjacent grazed habitats (Crouch 1981, Mosconi and Hutto 1981, Taylor 1986).

Neotropical migratory bird species have been found to be very sensitive to habitat change (Sedgwick and Knopf 1987, Knopf et al. 1988, Krueper 1993). Buttery and Shields (1975) stated that if riparian conditions are not suitable due to changes in key vegetative components, the stimulus to breed in one area may not be elicited. Once riparian habitat has been compromised through land use practices such as unmanaged livestock utilization, birds may simply vacate traditionally used riparian breeding habitats in search of suitable habitat elsewhere. Grazing pressure on vegetation has been shown to alter growth form, plant vigor and plant species composition, resulting in

increases or decreases in populations of bird species (Glinski 1977, Townsend and Smith 1977, Ryder 1980). Rucks (1978) stated that livestock grazing causes the replacement of shrub-nesting bird species with species showing no preference for vertical vegetative structure. Vegetative structural components such as foliage height diversity, total percent foliage cover, foliage volume, and plant species diversity are key factors determining the density and diversity of breeding birds (Balda 1975, Anderson and Ohmart 1984). Birds were found in lower numbers in habitats lacking high structural diversity and suitable number of mature trees. All of these key structural components of the vegetative community are directly impacted by unmanaged livestock practices to the detriment of avian populations. Especially impacted are ground nesting riparian obligate species such as Common Yellowthroat (*Geothlypis trichas*), Yellow-breasted Chat (*Icteria virens*), Abert's Towhee (*Pipilo aberti*), and Song Sparrow (*Melospiza melodia*), which have been shown to respond with significant if not spectacular population increases when livestock have been removed from riparian ecosystems such as within the San Pedro NCA (Krueper 1993).

Excessive livestock grazing can also affect types and abundance of food items for birds (Ryder 1980). Cattle and sheep have been shown to eat selected species of range and forest plants. These shelter mammal and insect populations which species of birds utilize as food. Small mammal populations are affected by high levels of grazing which benefit open habitat specialists such as deer mice, whereas various species of pocket mice and western harvest mice which prefer heavier cover are selected against. Raptors which utilize small mammals as prey may not choose to frequent submarginal riparian habitats for feeding due to lack of preferred prey items. Additionally, insect biomass may be decreased in riparian habitats which are heavily grazed due to lack of understory vegetation (Krueper pers. obs., R.D. Ohmart pers. comm. 1995). Insectivorous birds using riparian habitats for breeding and migratory habitat depend heavily on the annual insect biomass which is found in undisturbed riparian zones for feeding of young and for replenishing energy resources before continuing migratory movements. Annual and perennial grasses in riparian habitats are heavily utilized during the summer breeding season by many species of birds. During the late summer and fall migration period within the San Pedro Riparian National Conservation Area (NCA), avian species such as Black-headed Grosbeak (*Pheucticus ludovicianus*), Lazuli Bunting (*Passerina amoena*), Indigo Bunting (*Passerina cyanea*), Lincoln's Sparrow (*Melospiza lincolnii*) and Green-tailed towhee (*Pipilo chlorurus*) feed primarily on the seeds produced from grasses which are produced within the riparian zone during the summer growing season (Krueper pers. obs.). When cattle were present in the riparian habitat prior to a domestic livestock moratorium in 1988, little vegetation and seed production for granivorous bird species were noted. However, since the moratorium has taken effect, annual and perennial grasses in and adjacent to the riparian zone have greatly increased, and the resultant seed production currently attracts more granivorous bird species by a factor of ten over population densities before the livestock moratorium took effect (BLM files).

Bock et al. (1993) summarized results of previous studies of the avifauna of riparian woodlands of the West. Of the 43 avian species studied, 8 responded positively to grazing while 17 were negatively affected and the remaining 18 were unresponsive or showed mixed response. Neotropical migratory bird species which were most heavily impacted by livestock grazing were those which require dense understory vegetation for feeding or for nesting cover. Bock et al. (1993) noted that those species most critically impacted were Common Yellowthroat and Lincoln's Sparrow. Based upon known habitat requirements, they predicted that many of the other 18 species which showed mixed results actually would be negatively impacted from riparian grazing practices. In one of the largest studies in the Southwest monitoring avian response to a grazing moratorium, populations of Song Sparrow, Common Yellowthroat and Yellow-breasted Chat increased from five to ten-fold within 5 years after cessation of livestock grazing pressure (Krueper 1993).

Although Schultz and Leininger (1991) found that while American Robin (*Turdus migratorius*) benefitted from heavy grazing and the resultant open habitat, species such as Wilson's Warbler (*Wilsonia pusilla*) and Lincoln's Sparrow which require densely vegetated understory and

midstory for feeding and breeding requirements were much more common in ungrazed areas with abundant willows. Greater shrub cover in ungrazed habitats allowed much higher breeding densities of these avian species than in the grazed habitats.

While riparian neotropical migratory bird species use fragmented habitats in high densities, due to the limited extent of western riparian ecosystems, these species may actually have smaller overall populations than the neotropical migratory bird species which breed in more expansive eastern forests (Bock et al. 1993). This is cause for concern because even species which currently have high densities in southwestern riparian habitats are at risk of extirpation if the remaining quality and quantity of riparian ecosystems are compromised. DeSante and George (1994) documented 58 species of migratory landbirds which have decreased in the western United States during the past 26 years. Of this total, 16 species have declined as a direct result of riparian habitat destruction, and one of the primary factors attributed to these declines was overgrazing. Over forty percent of Arizona's state-listed bird species are considered to be riparian obligate species (Corman, Arizona Game and Fish Department, per. comm.). It becomes obvious why such a high percentage of the state total has been designated as such when one considers that historically less than 5% of the total land mass of Arizona was classified as riparian habitat. Of that total, over 95% has been destroyed or altered in a negative manner (Lofgren 1990). While many avian species teeter on the brink of becoming listed or extirpated, we must recognize that avian species declines are but the result of a much larger problem. Hunter et al. (1987) succinctly summarized the dilemma in saying:

> "the greatest problem afflicting effective riparian management throughout the Southwest, especially at lower elevations, is the attention given to single species at the expense of an entire community of species that is in trouble....Listing of any one species will not protect all other declining species...in the Southwest. A radical change in orientation is needed, from the piecemeal approach of protecting single species (which is still essential) to protecting habitats. Native riparian systems must be protected for what they are - endangered ecosystems. Only by river system management can we effectively stem the decline of our riparian avifauna...."

Conservation of neotropical migratory bird populations in the Southwest will continue to require protection and restoration efforts within riparian ecosystems.

Mammals

One of the least understood and least studied group of vertebrate animals using riparian habitats are small mammals. Livestock grazing impacts on avian populations have been fairly well documented. For the same reasons that understory bird species are affected by grazing in riparian habitats, small mammals have been shown to be similarly impacted. Shrews, voles and mice species which require thick understory vegetation and available water resources have been shown to decline under a riparian grazing regime (Johnson 1982, Medin and Clary 1990, Schulz and Leininger 1991, Clary and Medin 1992). Mammal species richness and diversity are significantly lower in many grazed riparian areas compared to ungrazed areas. Alternately, Johnson (1982) found that grazing increases the density of certain small mammal species which prefer low levels of vegetative cover. In these heavily utilized areas, small mammal species which require high levels of vegetative cover decreased significantly. Although this conclusion would seem to be obvious to the trained biologist, few studies have been conducted for the duration needed to generate hard data on impacts of livestock on small mammal populations.

It appears that quality of vegetation and vegetative composition within the community is more important in determining suitable habitat for small mammal communities than the availability of water (Cranford 1983, Schultz and Leininger 1990, 1991). When unmanaged livestock grazing removes vegetative cover from riparian habitats, small mammals will vacate the area regardless if available water is present. Thus, livestock grazing changes vegetative habitat structure which results in a shift in small mammal species composition in riparian habitats.

CONCLUSION

Preservation, protection and restoration of riparian habitats in the Southwest is of critical

importance because of their limited geographic extent and their extraordinary abundance and diversity of native wildlife. Domestic livestock grazing is the most widespread economic land use in the western United States. Livestock utilize public lands in all western states, from sea level to alpine habitats. Because of this situation, domestic livestock have now become the key element in the regulatory processes of nearly every Southwestern ecosystem. This situation has existed in the lowland Southwest for nearly 300 years despite the fact that large ungulates such as domestic cattle were not historically present in these habitats. Southwestern lowland riparian ecosystems evolved in the absence of the tremendous grazing pressures which now exist. Due to historic stocking levels and unmanaged grazing systems, many Southwestern riparian habitats have been permanently altered in their structural and functional integrity, resulting in loss of species diversity, richness and abundance.

Very little ecological management has occurred in Southwestern riparian habitats. Historic and current management of these sensitive ecosystems has traditionally centered around a concept of single-purpose consumptive utilization such as mining, timber harvest, water management, livestock production or hydroelectrical power. In the American Southwest, the predominant land use based upon total acreage under utilization, continues to be domestic livestock management. Numerous studies have shown that unmanaged livestock grazing results in serious deleterious impacts on native flora and fauna.

Riparian habitats are critical for wildlife and fish species in arid ecosystems. The Public Land Law Review Commission (1970) wrote "(t)he Federal Government has a responsibility to make provision for protecting, maintaining, and enhancing fish and wildlife values on its lands generally because of the importance of those values as part of the natural environment over and above their value for hunting, fishing and other recreational purposes." The health of these ecosystems is the best indicator of whether livestock management is in accordance with the multiple use mandate of the Federal Land and Policy Management Act of 1976. Sadly, these requirements are not being met in many riparian areas of the Southwest. Although the BLM and the USFS have been directed by the Public Rangelands Improvement Act of 1978 to improve declining range conditions, the agencies have been unable to meet the Congressional mandates of the Act. The BLM and the USFS have not been able to effectively administer an intensive livestock management program because these agencies do not have the capability in terms of staffing and funding. State land departments have an even worse track record for management of the lands they are entrusted with (Robert Ohmart 1995, pers. comm.)

Many vertebrate species have declined in recent years due to alteration of riparian habitats, and these species may soon be considered for Federal listing. To prevent future listings and to reverse population declines of sensitive wildlife species, land management agencies need to implement appropriate practices within riparian ecosystems. Recent riparian ecosystem recovery efforts have been shown to benefit many wildlife species and can be used as examples of balanced riparian ecosystem management.

A major hurdle which continues to impede riparian area management is mixed ownership patterns which fragment local communities and polarize "consumptive" and "non-consumptive" users alike. Private landowners may see riparian ecosystems as an opportunity for monetary gain, while others may choose to manage these systems in a natural, "hands-off" approach. Land management agencies such as the USFS and the BLM are mandated to administer public lands in a multiple-use manner provided that the impacts do not jeopardize the continued sustainable use of those lands. Herein lies the crux of the problem. Humans will always agree to disagree on management of "their" public lands, and why shouldn't they? Afterall, it is their public lands, to be enjoyed now and for future generations. The challenge is to strike a balance between consumptive needs and the needs of the general public. The only way this can be accomplished is using a consensus problem-solving process where management techniques and implementation are agreed upon by all affected parties. This has been shown to work, but it can be a lengthy process. Communication, understanding and acceptance of change for the integrity of the ecosystem and for the benefit of the greatest number of people are the answers. But how to get there...?

MANAGEMENT CONFLICT AND RESOLUTION

Aldo Leopold, as early as 1924 said that "grazing is the prime factor in destroying watershed values" in Arizona. Over seventy years later, grazing management practices are still impacting the rangeland and riparian ecosystems of the arid Southwest. Why has this continued to occur when so many dedicated public and private land owners have recognized the problem for so long? As with many new ideas, change is associated with unfamiliarity and a reticence to accept even the most basic truth in light of past mismanagement. We have known for decades that unmanaged livestock use in riparian habitats has caused great destruction, yet political pressures and institutional paradigms have made riparian habitat rehabilitation move at a snail's pace. Land managers must accept this reality, and yet continue to move forward in a progressive manner that addresses issues of riparian degradation in both a humane and biological context. We cannot simply force all cattle off of the public lands with a sweep of the pen, and we cannot expect ranchers to anonymously accept the inevitable changes which are on the horizon. Human acceptance of change will take time, but land managers must continue to work with their allottees to determine the best management practices possible for the health of riparian ecosystems and sustainability of their fragile resources.

Management Recommendations

1. Recognize that a problem does exist. Riparian ecosystems are uniquely sensitive habitats, and should not be managed as part of adjacent upland sites. Most management activities do not address riparian condition or recovery as their main objective. Riparian habitat should be managed as the most sensitive and most productive North American habitat.
2. Manage riparian systems for biological integrity rather than for domestic livestock utilization until desired ecological condition is restored.
   - The grazing management system designed for an area should be tailored to the conditions, problems, potential, objectives, and livestock management considerations on a site specific basis using the best information and science possible that will best meet the needs of the resources (Kinch 1989).
   - Whenever possible, exclude all grazing from riparian habitats to protect vegetation, wildlife and watershed values. Livestock should be permitted in riparian areas only if grazing contributes to the improvement of riparian health.
   - If riparian habitats are to be grazed, light to moderate use during the late fall and winter period are preferred.
   - Degraded riparian habitats may need complete rest for several years to initiate recovery. In most cases, only complete exclusion from the riparian zone can recover these habitats. While a system of rest-rotation can increase forage production, there is no conclusive evidence that it can completely recover a badly degraded riparian ecosystem. Desired Future Condition will **never** be achieved in an unmanaged livestock scenario.
   - Monitor results of vegetative and wildlife response regularly to determine if goals are being met. Change management as needed to achieve Desired Future Condition.
   - Allow extended non-use of grazing permits to protect sensitive or recovering riparian ecosystems and the wildlife these systems support.

Kinch (1989) correctly states that western riparian systems can be resilient under continued heavy livestock utilization and that these systems typically respond more quickly to management change than drier upland habitats. He further states that there is currently no single grazing management system that has conclusively proven to result in consistent improvement of degraded riparian areas in the western United States. It is widely accepted that historically less than 1% of the arid Southwest was composed of riparian habitat and that of that total an estimated 95% has been severely altered or destroyed. I would argue that because of the importance,

fragility and limited total riparian acreage that remains, all riparian habitats should be excluded from domestic livestock use until they recover their integrity and functionality within an ecosystem-based context. It is at this point that grazing be considered within western riparian systems, but only after wildlife, recreational and watershed values are adequately addressed.

Grazing allotment decisions are made at the national, resource area/forest, and allotment level. The public is entitled and encouraged to contribute input at all levels in the decision making process. The public must get involved in the formulation of land use plans. By actively influencing land management agency decisions, the public can bring a measure of balance and environmental concern to the management of the public lands. As responsible land managers, we need to insure that future generations don't inherit the same problems that the current generation has inherited (Wald et al. 1991). Local consensus and support are critical to successful riparian area management.

3. Monitor rates of recovery and potential impacts of adjacent land management practices. Domestic livestock grazing is but one of many management activities which impact riparian ecosystems. Other impacts which need to be monitored are recreation, mining, logging, mechanical manipulation of riparian habitats and urbanization.

4. Address the issue of "burden of proof." Do not assume that the Federal Land and Policy Management Act with it's multiple-use mandate automatically reads "all uses in all habitats unless you can prove it will have an adverse impact."

   - Consumptive users should bear the burden of proof to show that their activities will not impact sensitive riparian resources.

   - Adopt the concept of "appropriate use in appropriate habitats under appropriate circumstances." Management efforts should promote the biological integrity of the riparian ecosystem rather than political or economic gain. The use of one dominant resource activity should not be pursued to the exclusion of other equally important (although possibly not as financially lucrative) activities. Riparian ecosystems cannot be managed to achieve optimal production for all competing uses, and must be balanced among a great variety of uses.

5. Hold managers and permittees "accountable" for the health of the ecosystem.

   - Managers need to show riparian improvements in yearly appraisals. Protecting scenic, ecosystem, wildlife, recreation, cultural and hydrologic values are within the realm of mandated legal duties of the USFS and the BLM.

   - Permittees should receive incentives to rest pastures with riparian habitat. Grazing fees should be restructured to reward the rancher who is improving the health of riparian areas, and to avoid rewarding the rancher who continues to degrade these systems. Permittees who are achieving desired riparian objectives may pay less per animal unit month than permittees who are not achieving riparian objectives.

   - Land management agencies need to re-evaluate grazing systems within the context of sound biological principles and recognize that all riparian systems are unique. One management prescription will not apply to all systems. Each system requires thorough investigation, monitoring and management techniques which are tailored to that specific system. When change is required, land managers must have the biological and professional integrity to admit that change is needed, and then implement the change.

   - The preservation of functioning ecosystems and native floral and faunal species should be the primary goal of public land management.

The BLM and the USFS are mandated by the following laws to administer lands in a manner which does not compromise the integrity of the ecosystem health: the Taylor Grazing Act (1934); the National Environmen-

tal Policy Act (1970); the Endangered Species Act (1973); the Federal Land Policy and Management Act (1976); the Public Rangelands Improvement Act (1978); the Clean Water Act (1977 and 1987 amended); and BLM and USFS riparian area policies and mandates (various dates). The Endangered Species Act of 1973 was clearly intended to protect and recover all listed plant and wildlife species. The Act states that recovery of these species will be the highest priority for all land management agencies, and that this mandate would supersede the multiple-use mandates of the USFS and the BLM. Even with this guidance, public land management agencies have not been able to operate their range programs without meeting their mandates as directed by the Act.

6. Encourage research and monitoring using sound science to gather, synthesize and dispense information which will restore degraded riparian ecosystems and associated biotic resources.

7. Manage riparian ecosystems and associated nongame wildlife resources with established programs which utilize game species as a focal point for wildlife management. As Gottschalk (1975) stated: "(w)e have not yet reached the point in our public attitudes toward wildlife where we can assume support for fish and wildlife resources that have no obvious utility. Therefore the best approach will be to attempt to tie programs for nongame species into an overall ecological orientation. To do so will require changes in public policy dealing with our renewable wildlife resources, and in the system of training land and wildlife managers. Meanwhile such managers must do their best to become practical ecologists."

Domestic livestock grazing is undoubtedly the most ubiquitous land use within the western United States, and has been documented to have greatly influenced all aspects of the western landscape. Cooperrider (1990) stated that "since livestock grazing remains one of the most common and widespread uses of western rangelands, and since impacts of such grazing on biological diversity are so poorly understood, livestock grazing must be considered as one of the primary threats to biological diversity." Conservation of biological diversity within Western ecosystems is essential because the accumulated loss of populations and ecosystem fragments could result in the permanent disappearance of many plant and wildlife species as well as entire biological communities (Ehrlich 1987). Riparian habitats are an integral component of western biological ecosystems, and their loss could permanently impact the integrity of the land as well as all of the inhabitants which depend on the land, including plant, animal and human populations.

Aldo Leopold wrote that "to keep every cog and wheel is the first precaution of intelligent tinkering". One of the most integral "cogs" that must be preserved are the endangered riparian ecosystems of the Southwest. Riparian ecosystems are fragile corridors of life in the otherwise arid Southwest, and these systems link all other habitats together. Losing riparian habitats creates dysfunctional ecosystems. Unmanaged livestock utilization has resulted greatly in the dysfunctioning and destruction of riparian ecosystems in the Southwest.

I would warn land managers that if we do not address Southwestern riparian issues, and in particular continued unmanaged livestock utilization, then plant and wildlife species that are dependent on Southwestern riparian habitats will create issues which could bury the issues facing wildlife managers in the Pacific Northwest. While a Western Yellow-billed Cuckoo (*Coccyzus americanus occidentalis*), Southwestern Willow Flycatcher (*Empidonax traillii extimus*) or Mexican Garter Snake (*Thamnophis eques*) may not have the economic impact or political sensitivity of a Northern Spotted Owl (*Strix occidentalis*), they are a few among the scores of wildlife species which are now "teetering on the brink" in Southwestern riparian ecosystems. This issue has only recently been addressed, but it will eventually affect all future land use decisions and management of Southwestern riparian ecosystems.

We have thus far been using a piecemeal approach to riparian management, but with little success. We must determine the carrying capacity of a watershed before we compromise the quality of life and the ecosystem which sustains that quality of life. We have a choice as land managers. Continue to be reactive in our management techniques at the expense of many species, or be proactive to prevent extinctions and future listings of many wildlife species. It is our choice, but we no longer have the luxury of time.

LITERATURE CITED

Allen, L.S. 1989a. Roots of the Arizona livestock industry. Rangelands 11(1):9-13.

Allen, L.S. 1989b. Livestock and the Coronado National Forest. Rangelands 11(1):14-20.

Anderson, B.W., and R.D. Ohmart. 1977. Vegetation structure and bird use in the lower Colorado River Valley. Pp. 23-34 *in* Importance, preservation and management of riparian habitat: A symposium (proceedings). R.R. Johnson and D.A. Jones (tech. coords.), Tucson, AZ, July 9. USDA Forest Service Gen. Tech. Rep. RM-43.

Anderson, B.W., and R.D. Ohmart. 1984. Vegetation management study for the enhancement of wildlife along the lower Colorado River. Comprehensive final report to the U.S. Bureau of Reclamation. Boulder City, NV. 529 pp.

Balda, R.P. 1975. Vegetation structure and breeding bird diversity. Pp. 59-80 *in* Proceedings of the symposium on management of forest and range habitats for nongame birds. 6-9 May, Tucson, AZ. U.S.D.A. Forest Service Gen. Tech. Rep. WO-1.

Behnke, R.J. and M. Zarn. 1976. Biology and management of threatened and endangered western trout. USDA Forest Service Gen. Tech. Rep. RM-28. Rocky Mtn. For. and Range Exp. Stn., Fort Collins, CO. 45 pp.

Bock, C.E., V.A. Saab, T.D. Rich, and D.S. Dobkin. 1993. Effects of livestock grazing on Neotropical migratory landbirds in western North America. Pp. 296-309 *in* Status and management of neotropical migratory birds, D.M. Finch and P.W. Stangel (eds). 1992 September 21-25, Estes Park, CO. Gen. Tech. Rep. RM-229, Fort Collins, CO. U.S.D.A. Forest Service, Rocky Mountain Forest and Range Experiment Station. 422 pp.

Bull, E.L., and J.M. Slovlin. 1982. Relationships between avifauna and streamside vegetation. Transactions of the Forty-seventh North American Wildlife and Natural Resources Conference. 47:496-506.

Buttery, R.F., and P.W. Shields. 1975. Range management practices and bird habitat values. Pp. 183-189 *in* Proceedings of the symposium on management of forest and range habitats for nongame birds. 6-9 May, Tucson, AZ U.S.D.A. Forest Service Gen. Tech. Rep. WO-1.

Campbell, D. 1988. Pers, comm. The Nature Conservancy, Arizona Chapter. 300 East University Blvd., Suite 230, Tucson, AZ, 85705

Carothers, S.W., and R.R. Johnson. 1975. Water management practices and their effects on nongame birds in range habitats. Pp. 210-222 *in* Management of forest and range habitats for nongame birds (D.R. Smith ed.). U.S.D.A. Forest Service Gen. Tech. Rep. WO-1. Washington D.C.

Chaney, E., W. Elmore, and W.S. Platts. 1990. Livestock grazing on western riparian areas. Produced for the Environmental Protection Agency by Northwest Resource Information Center, Inc., Eagle, ID.

Clary, W.P. and D.E. Medin. 1992. Vegetation, breeding bird, and small mammal biomass in two high-elevation sagebrush riparian habitats. Pp. 100-110 *in* Proceedings - Symposium on ecology and management of riparian shrub communities. W.P. Clary, E. McArthur, E. Durant, D. Bedunah and C.L. Wambolt (eds.) 1991 May 29-31. Sun Valley, ID. USDA Forest Service Intermountain Research Station Gen. Tech. Rep. INT-289. 232 pp.

Corman, T.E. 1995. (pers. comm.). Arizona Game and Fish Department, Phoenix, AZ.

Cooperrider, A. 1990. Conservation of biological diversity on western rangelands *in* 55th North American wildlife and natural resources conference (proceedings), Mar 16-21. Denver, CO.

Cranford, J.A. 1983. Ecological strategies of a small hibernator, the western jumping mouse, *Zapus princeps*. Canadian Journal of Zoology 61:232-240.

Crispin, V.A. 1981. Stream rehabilitation of the West Fork, Deer Creek, Nevada. Bureau of Land Management. Elko, NV.

Crouch, G.L. 1981. Wildlife on ungrazed and grazed bottomlands on the South Platte River, Northeastern Colorado. Pp. 186-197 *in* Symposium on wildlife-livestock interactions (J.M. Peeks and P.D. Dalke eds). University of Idaho, Moscow..

Dahlem, E.A. 1979. The Mahogony Creek watershed - with and without grazing. Pp 31-34 *in* Proceedings of the forum - grazing and riparian/stream ecosystems. 3-4 November 1978, Denver, CO. Trout Unlimited Inc., (pub).

DeSante, D.F., and T.L. George. 1994. Population trends in the landbirds of western North America. Studies in Avian Biology No. 15:173-190.

Dobyns, H.F. 1981. From fire to flood. Ballena Press. Socorro, NM. 212 pp.

Ehrlich, P.R. 1987. Habitats in crisis. Wilderness 50(176):12-15.

Fleischner, T.L. 1994. Ecological costs of livestock grazing in western North America. Conservation Biology 8(3):629-644.

Fradkin, Philip. 1979. The eating of the West. Audubon Magazine, January.

Glinski, R.L. 1977. Regeneration and distribution of sycamore and cottonwood trees along Sonoita Creek, Santa Cruz County, Arizona. Pp. 116-123 *in* Importance, preservation and management of riparian habitat: a symposium (proceedings). R.R. Johnson and D.A. Jones (tech coords.), General Technical Report RM-43 Fort Collins, CO. U.S.D.A. Forest Service, Rocky Mountain Forest and Range Experiment Station. 217 pp.

Gori, D. 1992. Know your element: Cottonwood-willow riparian forests. The Nature Conservancy Arizona Chapter Newsletter. vol 14, no. 1. Tucson, AZ 12 pp.

Gottschalk, J.S. 1975. The challenge of practical ecology. Pp.2-5 *in* The proceedings of the symposium on management of forest and range habitats for nongame birds. 6-9 May, Tucson, AZ. U.S.D.A. Forest Service Gen. Tech. Rep. WO-1.

Hastings, J.R., and R.M. Turner. 1965. The changing mile. University of Arizona Press, Tucson, AZ.

Horning, J. 1994. Grazing to extinction: endangered, threatened and candidate species imperiled by livestock grazing on western public lands. National Wildlife Federation, Washington D.C., 68 pp.

Hunter, W.C., R.D. Ohmart, and B.W. Anderson. 1987. Status of breeding riparian-obligate birds in southwestern riverine systems. Western Birds 18(1):10-18.

Jennings, M.R. 1988. Natural history and decline of native ranids in California. pp. 61-72 *in* Proceedings of the conference on California herpetology. H.F. DeLisle, P.R. Brown, B. Kaufman, and B.M. McGurty (eds.). Southwestern Herpetologists Society Special Publication 4. 143 pp.

Jennings, M.R., and M.P. Hayes. 1993. Decline of native ranids in the desert Southwest. *in* Proceedings of the conference of herpetology of the North American deserts. P.R. Brown and J.W. Wright (eds.). Southwestern Herpetologists Society Special Publication 5.

Johnson, R.R. 1970. Tree removal along southwestern rivers and effects on associated organisms. Am. Phil. Soc., Yearbook 1970. Pp. 321-322.

Johnson, R.R., L.T. Haight, and J.M. Simpson. 1977. Endangered species vs. endangered habitats: a concept. Pp. 68-74 *in* Importance, preservation and management of riparian habitat: a symposium (proceedings). R.R. Johnson and D.A. Jones (tech coords.), General Technical Report RM-43 Fort Collins, CO. U.S.D.A. Forest Service, Rocky Mountain Forest and Range Experiment Station. 217 pp.

Johnson, R.R., and L.T. Haight. 1985. Avian use of xeroriparian ecosystems in the North American warm deserts. Pp. 156-160 *in* Riparian ecosystems and their management: Reconciling conflicting uses - First N. Am. Riparian Conference (proceedings), R.R. Johnson, C.D. Ziebell, D.R. Patton, P.F. Ffolliott, and R.H. Hamre (tech. coords.), USDA Forest Service Gen. Tech. Rep. RM-120.

Johnson, S.J. 1982. Impacts of domestic livestock grazing on small mammals of forest grazing allotments in southwestern Idaho. Pp. 242-250 *in* Symposium on wildlife-livestock interactions, J.M. Peeks and P.D. Dalke (eds.) University of Idaho, Moscow.

Kinch, G. 1989. Riparian area management: Grazing management in riparian areas. Tech. Ref. 1737-4, U.S.D.I. Bureau of Land Management, Denver, CO. 44 pp.

Knopf, F.L., J.A. Sedgwick, and R.W. Cannon. 1988. Guild structure of a riparian avifauna relative to seasonal cattle grazing. Journal of Wildlife Management 52:280-290.

Krueper, D. J. 1993. Effects of land use practices on western riparian ecosystems. Pp. 321-330 *in* Status and management of neotropical migratory birds, D.M. Finch and P.W. Stangel (eds); Gen. Tech. Rep. RM-229, Fort Collins, CO: U.S.D.A., Forest Service, Rocky Mountain Forest and Range Experiment Station: 422 pp.

Kuss, F.R., and C.N. Hall. 1991. Ground flora trampling studies: five years after closure. Environmental Management, vol 15 (5):715-727.

Lofgren, S. 1990. Final report and recommendations of the governor's riparian habitat task force (Executive Order 89-16, Streams and Riparian Resources). Report submitted to the Honorable Rose Mofford, Governor of the State of Arizona.

Lusby, G.C. 1979. Effects of grazing on runoff and sediment yield from desert rangeland at Badger Wash in western Colorado, 1953-73. U.S. Geol. Surv. Water Supply Paper 1532-I. 34 pp.

Martin, D.L. 1993. Sierra Nevada anuran survey: an investigation of amphibian population abundance in the national forests of the Sierra Nevada of California. Report V 1.0, Conorus Ltd. Ecological Research Team. 76 pp.

Medin, D.E. and W.P. Clary. 1990. Birds and small mammal populations in a grazed and ungrazed riparian habitat in Idaho. USDA Forest Service, Intermountain Research Station Res. Paper INT-425. Ogden, UT. 8 pp.

Mosconi, S.L. and R.L. Hutto. 1981. The effect of grazing on land birds of a western Montana riparian habitat. Pp. 221-233 *in* Symposium of wildlife-livestock interactions, J.M. Peeks and P.D. Dalke (eds.). University of Idaho, Moscow.

Noss, R.F. 1994. Cows and conservation biology. Cons. Biology, Vol 8(3):613-616.

Ohmart, R.D. 1994. The effects of human-induced changes on the avifauna of western riparian habitats. Studies in avian biology no.15:273-285.

Ohmart, R.D. 1995. Historical and present impacts of livestock grazing on fish and wildlife resources in western riparian habitats (manuscript). Center for Environmental Studies, Arizona State University, Tempe, AZ. 115 pp.

Ohmart, R.D. 1995. (Pers. comm. June 28 re: current condition of Southwestern riparian ecosystems). Center for Environmental Studies, Arizona State University, Tempe, AZ.

Platts, W.S. and R.L.Nelson. 1985. Stream habitat and fisheries response to livestock grazing and instream improvement structures, Big Creek, Utah. J. Soil and Water Cons. Vol 40(4):374-379.

Platts, W.S. 1991. Livestock grazing. pp.389-423 in W.Rr. Meehan (ed.). Influences of forest and rangeland management on salmonid fishes and their habitats. American Fisheries Society Special Publication 19. Bethesda, MD. 751 pp.

Public Land Law Review Commission. 1970. One third of the nation's land: a report to the President and to the Congress by the Public Land Law Review Commission. U.S. Govt. Prin. Off., Washington D.C. 342 pp.

Rauzi, F. and F.M. Smith. 1973. Infiltration rates: three soils with three grazing levels in northeastern Colorado. J. Range Manage. 26:126-129.

Rinne, J.N., and W.L. Minckley. 1991. Native fishes of arid lands: a dwindling resource of the desert Southwest. Gen. Tech. Rep. RM-206. Ft. Collins, CO. U.S.D.A. Forest Service, Rocky Mountain Forest and Range Experiment Station. 45 pp.

Rucks, J.A. 1978. Comparisons of riparian communities influenced by grazing. Pp. 100-113 *in* Lowland river and stream habitat in Colorado: a symposium. Colorado Wildlife Society and Audubon Council.

Ryder, R.A. 1980. Effects of grazing on bird habitats. Pg 51-66 *in* Management of western forests and grasslands for nongame birds. U.S.D.A. Forest Service General Technical Report INT-86.

Schultz, T.T., and W.C. Leininger. 1990. Differences in riparian vegetation structure between grazed areas and enclosures. Journal of Range Management 43:294-298.

Schultz, T.T., and W.C. Leininger. 1991. Nongame wildlife communities in grazed and ungrazed montane riparian sites. Great Basin Naturalist 51(3):286-292.

Sedgwick, J.A., and F.L. Knopf. 1987. Breeding bird response to cattle grazing of a cottonwood bottomland. Journal of Wildlife Management 51:230-237.

Sprunt, A. 1975. Habitat management implications during migration. Pg 81-86 *in* Proceedings of the symposium on management of forest and range habitats for nongame birds. 6-9 May, Tucson, AZ. U.S.D.A. Forest Service Gen. Tech. Rep. WO-1.

Stephens, L.E., B.T. Brown, J.M. Simpson, and R.R. Johnson. 1977. The importance of riparian habitat to migrating birds. Pg. 156-164 *in* Importance, preservation and management of riparian

habitat : A symposium (proceedings). R.R. Johnson and D.A. Jones (tech. coords.), Tucson, AZ. July 9. USDA Forest Service Gen. Tech. Rep. RM-43.

Stoddart, L.A., A.D. Smith, and T.W. Box. 1975. Range Management. 3rd edition, McGraw-Hill Book Co., New York, 352 pp.

Szaro, R.C. 1980. Factors influencing bird populations in southwestern riparian forests. Pp. 403-418 *in* Management of western forests and grasslands for nongame birds (R.M. DeGraff, tech. coord.). U.S.D.A. Forest Service Gen. Tech. Rep. INT-86. Intermountain Forest and Range Experiment Station, Ogden, UT.

Szaro, R.C., and M.D. Jakle. 1985. Avian use of a desert riparian island and its adjacent scrub habitat. Condor 87:511-519.

Szaro, R.C., S.C. Belfit, J.K. Aitkin, and J. Rinne. 1985. Impact of grazing on a riparian garter snake. pp. 359-364 *in* Riparian ecosystems and their management: reconciling conflicting uses. USDA Forest Service Gen. Tech. Rep. RM-120.

Taylor, D.M. 1986. Effects of cattle grazing on passerine birds nesting in riparian habitat. J. Range Management 39(3):254-258

Thomas, J.W., C. Maser, and J.E. Rodiek. 1979. Wildlife habitats in managed rangelands - the Great Basin of southeastern Oregon: riparian zones. General Technical Report PNW-80, Portland, OR. U.S.D.A. Forest Service, Pacific Northwest Forest and Range Experiment Station. 18 pp.

Toone, R.A. 1991. General inventory of western spotted frogs in the House Range Resource Area, Utah. Richfield District, Bureau of Land management. 40 pp.

Townsend, J.E., and P.J. Smith. 1977. Proceeding of a seminar on improving fish and wildlife benefits in range management. U.S.D.I., Fish and Wildlife Service, Washington D.C., FWS/OBS-77/1, 118 pp.

U.S.D.I., Bureau of Land Management document. Riparian-Wetland Initiative for the 1990's. September 1991. U.S. Department of the Interior, Bureau of Land Management, 1849 C St., N.W., Washington D.C. 20240.

Wagner, F.H. 1978. Livestock grazing and the livestock industry. Pp. 121-145 *in* H.P. Brokaw (ed.) Wildlife and America. Council on Environmental Quality, U.S. Gov. Print. Office. 532 pp.

Wald, J., K. Rait, R. Strickland, and J. Feller. 1991. How not to be cowed (Livestock grazing on the public lands: an owner's manual). Natural Resources Defense Council, Quality Press, Salt Lake City, UT., 70 pp.

Wiens, J.A. and M.I. Dyer. 1975. Rangeland avifaunas: their composition, energetics, and role in the ecosystem. Pp. 146-182 *in* Proceedings of the symposium on management of forest and range habitats for nongame birds. U.S.D.A. Forest Service Gen. Tech. Rep. WO-1.

Wuerthner, G. 1993. Grazing myths: a top 10 list. Earth Watch, July, pp. 17-19.

Wuerthner, G. 1994. Subdivisions versus agriculture. Conservation Biology 8:905-908.

Desirable functional processes: A conceptual approach for evaluating ecological condition

Alvin L. Medina[1], Malchus B. Baker[2], Jr., and Daniel G. Neary[3]

Abstract.—Determining what "desired future condition" actually means has been viewed as a moving target approach for developing ecosystem management plans. The difficulty arises from trying to define what the desired condition are for any given site. In addition, definitions may be plagued with inconsistencies, contention and argument, indeterminate time frames, and less than the best knowledge available. Herein, we propose a conceptual approach called "Desirable Functional Processes," or DFP, for evaluating the ecological condition of an ecosystem or parts thereof. It is founded on the premise that ecosystems and their components display varied degrees of functionality. It is based on the degree to which one can observe the interaction of ongoing processes involving the vegetation, soils, and hydrological components that determine the functionality of the system. Hence, an ecosystem or its components are considered functional if the processes observed are those that move the system to a higher state of dynamic equilibrium, as opposed to a state that is dysfunctional and demonstrates a trend towards system degradation. The identification of processes and their functional status requires a multidisciplinary approach, wherein most elements of the environment are examined to determine functioning condition. Examples using a watershed approach are used to illustrate the concept and its framework. As a concept, it recognizes the public's needs in the decision-making process, and as such provides a mechanism by which the resource managers can communicate environmental concerns in a non-argumentative manner.

INTRODUCTION

A resource manager's decision of what he wants ultimately determines what he gets. This view of reality catalyzes current thought about how to manage our natural resources most effectively. The USDA Forest Service has adopted this concept as policy and as a framework to guide resource management of our national forests and grasslands (Robertson 1992, Kaufmann et al. 1994). Ecosystem science provides the foundation of ecosystem management, which connects the basic and applied sciences of the natural world with human factors (Pastor 1995). Resource managers employ tools such as the Integrated Resource Management Model to reach consensus about what an ecological site/unit should look like, be managed for, or to be the desired future condition (USDA Forest Service 1993). As a management concept, desired future condition (DFC) describes the character of the ecological unit for a given time and space. The description reflects environmental criteria deemed desirable by resource managers and the public.

DFC is more described than defined because the specific context is arguable. Different resource

[1]Research Ecologist, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Flagstaff, AZ.

[2]Research Hydrologist, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Flagstaff, AZ.

[3]Project Leader and Research Soil Scientist, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Flagstaff, AZ.

managers often hold different views about the resources for which an ecological unit should be managed and about how the unit should look. Consequently, traditional management objectives become a moving target, which is fundamentally unachievable because ecosystems are constantly changing. Therefore, predicting an outcome of management activity is difficult.

Another problem with DFC is the time period needed to achieve it. Some DFC's are achievable in months or years. However, others are probably beyond the time frame of land management plans, and well beyond the careers and lifetimes of the managers. DFC's of short term are realizable but those beyond 25 years are subject to change as society's needs or desires change. Hence, the latter are apt to become moving targets.

We propose an alternative context for the concept of desired future condition. Our context shifts the emphasis from the desired outcome to the essential process of achieving the outcome. The desirable functional processes (DFP) context focuses on the natural processes and natural functions that define individual ecological units. The processes include physical, chemical, and biotic components sustained through time and over space. A holistic management concept, DFP uses the best current knowledge to examine specific functions and processes of an ecological unit. Both basic and applied knowledge are interpreted into criteria that holistically describe the observed functions and processes. Management emphasizes achieving functionality of an ecological unit rather than maintaining a set of predefined, static, environmental conditions as in DFC. As a management concept, DFP provides a mechanism by which an ecological unit can be assessed in relative terms of functionality, with the understanding that data must be periodically collected and analyzed to reassess functionality. In this context, the DFP concept allows managers to assess the functional condition of an ecological unit at any point in time and to continue managing justifiably within the limits of the current knowledge and societal needs.

DFP assesses the whole ecological unit at any scale whether landscape, forest, habitat, or site. The DFP concept assumes that if ecological units of the lower levels, e.g. site, are functional, then the next larger hierarchical level is also functional or will become functional. The rationale is that processes operating at one scale can affect others at another scale (Gregory et al. 1991). The over riding question is simply this: Is the ecological unit functional or are parts thereof dysfunctional? Also, in DFP, inventory data are used to define the functional condition of an ecological unit. After a specific element has been determined to be dysfunctional, that element gets identified as a potential focus of management goals and activities. As such, DFP is considered a component of ecosystem management. It is principally focused on the functionality of the environment and on human activities that become modifiers of the functional condition of an ecological unit. In simple terms, DFP is the quantitative diagnosis of ecological units. Managers can utilize this science-based approach as well as other components of ecosystem management such as social and economic analyses to improve their decision making. The concept of desired future condition was seemingly intended to be like DFP (USDA Forest Service 1992) in its intentions, but rather has caused confusion in terms of its definition of a set of static conditions versus functionality.

The concept of DFP is not new but is based upon some of the rationale used in the Bureau of Land Management concept of determinating proper functioning condition for riparian areas (Barrett et al. 1993, Bridges et al. 1994). We seek to advance the concept to include all types of ecological units. However, for the purpose of illustration in this paper, we will limit discussion to a lotic riparian ecosystem as an example. To do this, we have modified and developed criteria in a format that invokes examination of five basic components of any ecological unit: air, water, soil, plants, and animals. Specific criteria are listed under each component to specify the principal and characteristic attributes and processes that determine the functional status of an ecological unit.

BACKGROUND

The primary intent of DFP is to focus resource management on a holistic approach to viewing an ecological unit in terms of functionality. In essence, DFP is a form of bio-indication, except physical factors can play a greater role than biotic or chemical factors in some cases. Vegetation generally is

the main biotic indicator that expresses the combined interactive effects of physical, chemical, and biotic factors (Zonneveld 1983). Given the impracticality of knowing everything about any ecosystem, it makes sense to initiate a process of functional assessment that is

1. Based on the best current state of ecological knowledge,
2. Flexible enough to accommodate new data, and
3. Applicable at any ecological scale.

Because our present technology often precludes measuring complex interactions that are of interest, we must rely on bio-indicators to express the sum of many individual interactions over time and space (Zonneveld 1983). In this sense, DFP utilizes biotic, hydrologic, and geomorphic indicators to express an environmental condition that is ecologically favorable in terms of site sustainability and productivity. The criteria are qualitative but are based on quantitative assessments of the ecological unit.

Other wetland/riparian scientists have proposed conceptual models for evaluating the functional condition for riparian or wetland areas, generally for specific agency needs. All such models are based on functional relationships and processes, such as those for the hierarchical classification of drainage basins (Frissell et al. 1986) or specifically for wetlands (Brinson 1993). Brinson's model focuses on fundamental processes essential for sustaining wetland ecosystems. Gregory et al. (1991) proposed a model of riparian zones that integrated the physical processes that shape valley-floor landscapes, the succession of terrestrial plant communities on these geomorphic surfaces, the formation of habitat, and the production of nutrition resources for aquatic ecosystems. A major argument made is that despite spatial and temporal differences between systems, fundamental ecological links that are functionally the same do exist. Smith (1992) and Ainslie (1994) proposed functional models for assessing wetlands based upon functional indicators for use in a regulatory arena of Section 404 of the Clean Water Act. The riparian models developed by the Bureau of Land Management (Barrett et al. 1993, Bridges et al. 1994) are examples of models highly applicable to most if not all regions of the U.S. Some models are specific in context, such as those proposed for aquatic macroinvertebrates (Hawkins and Sedell 1981) or wetland plants (Boutin and Keddy 1993). Reid (1994) presented a framework for evaluating cumulative watershed effects. This treatise contains many citations that are used to derive functional processes of watersheds in particular. Many of these models have not gained acceptance because, as Smith (1992) noted, of concerns over technical validity, time required to gain technical proficiency, and a limited number of functions assessed owing to limited databases. In general, the search for a conceptual approach toward assessing ecological units continues because of the immense need to have a scientifically reliable and defensible protocol that will expedite and alleviate the regulatory workload (NEPA, Clean Water Act Section 404, Endangered Species Act, etc.) placed on resource managers. To date, the better approaches are those models based on an expert systems approach such as that proposed by Gebhardt et al. (1989) and with specific criteria for the ecological unit in question.

ELEMENTS OF DFP

A key element of the DFP concept is the term "functional." An ecological unit is considered functional if the processes observed are those that move the system to a higher state of dynamic equilibrium, as opposed to one that is dysfunctional and demonstrates a trend toward system degradation. An ecological unit can always be described as functioning, but the important point here is whether the processes that exhibit the function are of the type that enhance the balance of the system and sustain the productivity of the unit. For example, degradation of a stream channel is an interactive hydrologic process that results in channel downcutting, lowering of the water table, and eventually loss of productivity of the riparian zone. In this case, the extent to which degradation occurs and the period within which it occurred would constitute a dysfunctional condition. A functional condition for this example would be one in which a quasi-equilibrium exists between degradational and aggradational processes that maintains the channel and water table in a steady state over time. The processes are measurable by monitoring.

When determining functioning condition, it is important to determine the condition of the entire watershed that influences the site being studied. The whole watershed can influence the quality, abundance, and stability of downstream resources by controlling production of sediment and nutrients, influencing ponding frequency and duration, and modifying the distribution of inorganic and organic chemicals (Barrett et al. 1993). To understand how an ecological site functions and to implement proper management practices, its capability and potential must be understood (Barrett et al. 1993). Capability is defined as the highest ecological status a site can attain given political, social, or economical constraints, often called limiting factors. Potential, often referred to as the potential natural community, is defined as the highest ecological status a site can attain given no political, social, or economical constraints. The capability and potential of a site is determined by the interaction of the air, water, soil, plants, and animals.

Use of the term "ecological site" is consistent with Leonard et al. (1992), who define it as follows:

Ecological site = *f* {soil, parent material, relief, climate, animals, time},

where time is the period needed for the biotic community to obtain a dynamic equilibrium with given soil and climate conditions.

Another definition of ecological site is "a kind of land with specific physical characteristics which differs from other kinds of land in its ability to produce distinctive kinds and amounts of vegetation and in its response to management" (Society for Range Management 1995). Unless otherwise specified, reference to ecological unit is meant to be applicable at the ecological site level, which is the preferred basis for inventories, assessments, and extrapolation of research and management experience.

The assessment of functionality of an ecological unit is not based on Clementsian successional theory. We concur with the Society for Range Management (1995) viewpoint that interpretations of successional status are inadequate to assess whether ecological units are properly protected from site degradation, meeting management objectives, or other characteristics related to biological diversity or nutrient cycling. Furthermore, ecological site status and health of the system are not necessarily one and the same (Gebhardt et al. 1990). Ecological site status is a position on a successional scale that may describe the site. The DFP concept allows an examination of the processes occurring within an ecological unit. Conducted as an assessment, the examination reveals the degree of functionality expressed by individual components of the site. An ecological unit may be at the pioneer level on the successional scale and yet exhibit a high degree of desirable functional processes. As well, an ecological unit may be ranked as climax and exhibit varied degrees of functionality, depending on the present state of the unit.

The term "desirable" is judgmental in context, but its use is founded on assumptions that the manager's goal is to achieve the objectives set forth under the philosophy of ecosystem management, one of which is to manage our natural resources for sustained productivity and diversity (Overbay 1992). As such, functions and processes that produce ecological conditions that enhance and sustain site productivity are regarded as desirable and based on the laws of ecology (Zonneveld 1983).

SPECIFIC COMPONENTS OF DFP

We recognize five basic components that need to be considered when assessing the functional condition of an ecological unit: air, soil, water, plants, and animals. All are essential interactive elements and no emphasis is placed on dominance. A requirement for assessing functional condition is an interdisciplinary understanding of the natural histories of plants and animals, soils, hydrology, geomorphology, and other disciplines. An interdisciplinary team is necessary to analyze the various parameters that provide basic information about the status of the ecological unit. When experience or an expert system is lacking, then far more environmental data are needed to appropriately determine functional condition. DFP utilizes existing databases and models for assessing functional condition.

An example for riparian areas is Rosgen's (1994) stream classification, which permits one to classify the existing condition of a stream and with additional hydrological data, e.g. pebble counts

(Bevenger and King 1995), determine specific elements that are functional or dysfunctional. A braided channel (D type) is an example of a dysfunctional condition, where more sediment has been deposited in the channel than the hydrologic component can process. An analysis using pebble counts would provide insight into recent changes in type and size of sediments also being deposited. The cause could be traced back to the source and found to be roads, grazing or some other disturbance activity.

Another model that could be applied is the concept of functional plant groups described by Grime (1979). This model examines the primary strategies used by plants to function within a given habitat, as competitors, stress tolerators, and ruderals. In a disturbed site, ruderals are generally abundant, whereas competitors would be much less abundant. Stress-tolerant competitive species such as Nebraska sedge (*Carex nebraskensis)* are an example of a key native, aquatic/riparian plant tolerant of flooding to mesic soil conditions (Medina, this issue). Kentucky bluegrass (*Poa pratensis*) would be an example of an exotic competitor in a riparian system. In this example, Nebraska sedge is a species indicative of a functional condition and Kentucky bluegrass is indicative of a dysfunctional condition.

Tables 1-5 contains specific criteria to be examined in assessing functional condition. The criteria are not all inclusive at this point but serve to illustrate the utility of DFP. Much of the information suggested by Barrett et al. (1993) in their model is used here, with additional criteria.

APPLICATION OF DFP

DFP applies whenever an ecological unit is being assessed for functional conditions. The criteria listed in Tables 1-5 were derived specifically for a riparian site. However, criteria can be derived for other sites. Depending on the discipline relevant to the site, specific information is collected and analyzed. Analyses of data are the basis for determining the functional condition of the site relative to a specific component.

These data will also identify specific elements of a component that are not functional. For example, if one or more criteria are not met, then this is an element that requires priority attention and is addressed accordingly in the Integrated Resource Management process as a management goal. The latter has been defined (by default) from the data analyses. As such, elements identified as dysfunc-

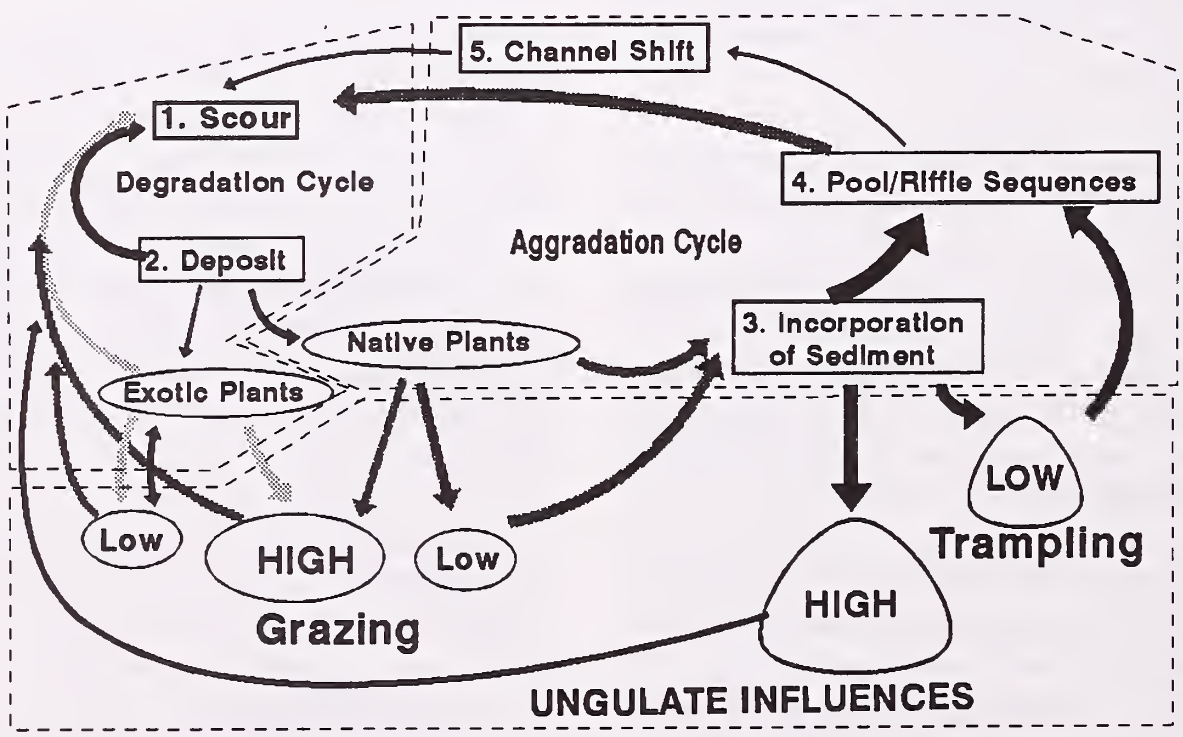


Figure 1. A conceptual model illustrating the interactions between physical and biotic components of a montane riparian meadow.

Table 1. Preliminary list of vegetation criteria that signify a functional condition for a riparian system.

Plants—Vegetative components	Yes	No	N/A
Composition—native herbaceous, aquatic plants, (sedges, rushes, etc) dominant on streambanks			
Composition—species present are native and indicative of soil moisture conditions for the site			
Composition—woody plants do not contribute to streambank erosion			
Structure—vegetation is multi-age			
Structure—riparian area has an adequate source of coarse and/or large woody debris			
Cover/Density—cover sufficient to protect banks during high flows; complete coverage of soil surface when plants are laid prostrate			
Vigor—plants exhibit vigorous growth of roots and aboveground biomass			

Table 2. Preliminary list of hydro/geomorphologic criteria that signify a functional condition for a riparian system.

Water—Hydro/Geomorphic components	Yes	No	N/A
Channel type — is of the appropriate type for the landscape setting, i.e. W/D ratios, sinuosity, etc.			
Bedload — is in balance with flow and sediment supply, with no net change in geomorphology			
Flow — instream flows maintained			
Flow — floodplain inundated during relatively frequent events (1-3 years)			
Morphology — upland watershed not contributing to channel degradation			
Water Table — s maintained at level adequate to sustain native riparian/aquatic vegetation			
Water Table — sustains site productivity at high level			
Structure — active/stable beaver dams			
Structure — instream substrates do not significantly change in composition between years			
Structure — floodplain characteristics (i.e., rocks, coarse and/or large woody debris) adequate to dissipate flow energies			
Structure — point bars are colonized by plants			
Morphology — lateral stream movement is associated with natural adjustments to stream-channel-flow conditions			

Table 3. Preliminary list of soil quality/erosional criteria that signify a functional condition for a riparian system.

Soil—Soil quality/Erosional components	Yes	No	N/A
Moisture regime — mesic to hydric, with periodic saturation to the surface			
Nutrient Cycling — adequate to sustain rapid plant growth, no deficiencies			
Organic Matter — accumulating or in equilibrium, not oxidizing			
Infiltration — depending on soil texture, at the high end of the range, exceeds most rainfall intensities			
Density — generally <1.2g/cc, decreasing with incorporation of organic matter			
Pore Space — contains macropores as a percent of pore volume			
Erosion — soil surfac e aggrading due to plant growth			
Erosion — rills and gullies not present			

Table 4. Preliminary list of air quality criteria that signify a functional condition for a riparian system.

Air — Air quality components	YES	NO	N/A
Deposition — particulate deposition of oxide compounds is insignificant			
Deposition — air-borne deposits from mines not present			
Deposition — wind eroded, deposited or transported particulates absent			

Table 5. Preliminary list of animal-effects criteria that signify a functional condition for a riparian system.

Animal — Animal effects components	YES	NO	N/A
Trampling — ungulate trampling does not significantly increase soil bulk density between years			
Trampling — ungulate trampling does not significantly change the structure of the plant community			
Trampling — ungulate use of streambanks does not significantly alter and/or impede geomorphological development of streambank-channel geometry			
Herbivory — herbivory within the streambank zone is within acceptable limits to sustain bank stability and site productivity			
Herbivory — herbivory within the riparian zone is within acceptable limits to sustain site productivity			
Density — animal density does not significantly affect plant composition of the riparian community			
Density — animal density does not significantly change the structure of the plant community			

tional become the projects or targets and identify where expenditure of monies could occur. Barrett et al. (1993) identify this stage as a condition known as "functional - at risk," meaning that the overall condition of the ecological unit is subject to dysfunctionality if the individual elements are not restored to fully functional. This equates, for example, to having a functional condition but grazing is at an unacceptable level.

Neary and Medina (this issue) illustrate the function and processes occurring within a montane riparian meadow in Figure 1. In this model, major hydrological, geomorphological, and biological processes occur continuously to produce a functional condition. The erosional processes of degradation (scour) and aggradation (deposit) in union with the water flow produce an instream effect resulting in a unique channel geometry. Sediments are exported based on the system's inherent flow characteristics, while other sediments are incorporated into the channel and streambanks through the interaction of riparian vegetation, channel gradient, and flows. In time, aquatic vegetation establishes on the streambanks to produce an additional interaction between the previous physical components. This biotic component serves as an agent of resistance against the erosive forces of the physical components. An additional biotic component (animals) can be added to produce other interactions between the biotic, physical, and chemical components of the system. In the case of the latter, excessive use by animals results in an adverse effect on the vegetative component, which in turn results in lowered erosive resistance, and finally resulting in geomorphological changes within the channel.

The efficacy with which DFP is employed depends on the individual and collective skills of the interdisciplinary team. An interdisciplinary team is a requirement (Barrett et al. 1993, Bridges et al. 1994) because of the tremendous amount of knowledge and experience that is required to provide a concise assessment. The long-term goal is to develop an expert system with the capacity to inventory and interpret diagnostic data into meaningful assessment criteria of functional condition. A by-product is the identification of priority concerns that should be the mandate for field projects. The concept, as stated before, is still in developmental form to incorporate all facets of any

ecological unit. DFP requires extensive thought on behalf of the resource professional to visualize the ecological unit in a holistic context.

To determine functionality of an ecological site, its capability and potential must be determined. One approach to take is the following (Barrett et al 1993):

- Look for relic areas (exclosures, preserves, etc).
- Seek historic photos, survey notes, and/or documents that indicate historic condition.
- Search for species lists (animals and plants, historic and present).
- Determine species habitat needs (animal and plants) related to species that are/were present.
- Examine soils and determine if they were saturated at one time and are now well drained.
- Examine the hydrology; establish the frequency and duration of flooding/ponding.
- Identify vegetation that currently exists. Are they the same species that occurred historically? In what proportions?
- Determine the entire watershed's general condition and identify its major landform.
- Look for limiting factors, both human-caused and natural, and determine if they can be modified.

Some sites will be prevented from achieving their potential because of limiting factors such as human activities. However, most limiting factors can be changed through proper management.

An ecological site is functioning properly (Barrett et al 1993) when adequate vegetation, landform, or debris are present to:

1. Dissipate energies associated with wind or water, thereby reducing erosion and improving water quality;
2. Filter sediment, capture bedload, and aid floodplain development;
3. Improve flood-water retention and groundwater recharge;
4. Develop root masses that stabilize channel banks against cutting action;
5. Develop diverse ponding characteristics to provide habitat and water depth, duration, and temperature necessary for fish production, waterbird breeding, and other uses;
6. Support greater biodiversity; and
7. Produce commodities desired by society at a rate commensurate with ecosystem function.

A key concept to remember is that all sites, such as riparian-wetland areas have fundamental commonalities in how they function, but they also have their own unique attributes. Similar riparian-wetland areas can and do function quite differently. As a result, most areas need to be evaluated against their own capability and potential. Even for similar areas, human influence may have introduced components that have changed the area's capability and potential. These factors and the uniqueness of each system must be considered to assess an area correctly.

To the extent that a resource manager uses DFP as a tool to base environmental decisions, such decisions are ultimately strengthen by the additional information provided from the public. DFP does not preclude or diminish the public's voice in management of resources. DFP provides the basis from which the public can be informed as to current environmental conditions in an improved, understandable, and non-argumentative manner. Everyone can agree to having functional conditions, but few can agree much less define a set of prescribed conditions owing to individual perspectives.

In conclusion, the concept of desirable functional processes is better for assessing the status of an ecological unit because it focuses on the natural processes and natural functions that define the ecological unit. DFP is adaptable to changing conditions in the status of the best current knowledge, recognizing that we don't know everything about our environment. The management emphasis is on achieving functionality of ecological units rather than attempting to reach a predefined, static, environmental condition as in DFC. DFP is dependent on collection of environmental data and a sound analysis thereof in order to best describe the functional criteria to be used in resource as-

sessments. These assessments are used by the resource manager to determine justifiable courses of action within the limits of the current knowledge and societal needs. Moreover, DFP is in keeping with the spirit of ecosystem management and the sustainability of ecosystems (USDA Forest Service 1992, Kaufmann et al. 1994).

LITERATURE CITED

Ainslie, William B. 1994. Rapid wetland functional assessment: its role and utility in the regulatory arena. Water, Air and Soil Pollution 77:433-444.

Barrett, Hugh, Jim Cagney, Ron Clark, Jim Fogg, Karl Gebhart, Paul L. Hansen, Brenda Mitchell, Don Prichard, and Dan Tippy. 1993. Riparian area management TR 1737-9: Process for assessing proper functioning condition. USDI Bureau of Land Management, Denver, CO. Technical Reference 1737-9. 60p.

Bevenger, Gregory S. and Rudy M. King. 1995. A pebble count procedure for assessing watershed cumulative effects. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO. RM-RP-319. 17p.

Bridges, Clay, Warren Hagenbuck, Russ Krapf, Steve Leonard, and Don Prichard. 1994. Riparian area management TR 1737-11: process for assessing proper functioning condition for lentic riparian-wetland areas. USDI Bureau of Land Management, Denver, CO. Technical reference 1737-11. 46p.

Brinson, M. M. 1993. A hydrogeomorphic classification for wetlands. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS. Technical Report WRP-DE-4.

Boutin, Celine and Paul A. Keddy. 1993. A functional classification of wetland plants. Journal of Vegetation Science 4:591-600.

Frissell, C. A., W. J. Liss, C. E. Warren, and M. C. Hurley. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10:199-214.

Gebhardt, Karl, Mark Vinson, William S. Platts, and William Jackson. 1989. Using expert systems in riparian management. pp 187. In R.E. Gresswell et al. (eds.), Riparian resource management: an educational workshop. May 8-11, 1989, Billings, MT. UDSI Bureau of Land Management.

Gebhardt, Karl, Steve Leonard, George Staidl, and Don Prichard. 1990. Riparian area management: Riparian and wetland classification review. USDI Bureau of Land Management, Denver, CO. Technical Reference 1737-5. 56p.

Gregory, Stanley V., Frederick J. Swanson, W. Arthur McKee, and Kenneth W. Cummins. 1991. An ecosystem perspective of riparian zones: focus on links between land and water. BioScience 41(8):540-551.

Grime, J. P. 1979. Plant strategies and vegetation processes. Wiley, New York. 222p.

Hawkins, C. P. and J. R. Sedell. 1981. Longitudinal and seasonal changes in functional organization of macroinvertebrate communities in four Oregon streams. Ecology 62:387-397.

Kaufmann, M. R., R. T. Graham, D. A. Boyce, Jr., W. H. Moir, L. P. Perry, R. T. Reynolds, R. L. Bassett, P/ Mehlhop, C. B. Edminster, W. M. Block, and P. S. Corn. 1994. An ecological basis for ecosystem management. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, CO. Gen. Tech.Rep. RM-246. 22p.

Leonard, S., George Staidl, Jim Fogg, Karl Gebhart, Warren Hagenbuck, and Don Prichard. 1992. Riparian area management TR 1737-7: Procedures for ecological site inventory — with special reference to riparian-wetland sites. USDI Bureau of Land Management, Denver, CO. Technical Reference 1737-7. 135p.

Neary, Daniel G. and Alvin L. Medina. 1996. Geomorphic response of a montane riparian habitat to interactions of ungulates, vegetation, and hydrology In USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, General Technical Report, Fort Collins, CO, this issue.

Overbay, J. C. 1992. Ecosystem management. pp3-15. In: Proceedings of the national workshop: taking an ecological approach to management. April 27-30, 1992, Salt Lake City, UT. USDA Forest Service, Washington D.C. Watershed and Air Management WO-WSA-3.

Pastor, John. 1995. Ecosystem management, ecological risk, and public policy. BioScience 45(4):286-288.

Reid, Leslie M. 1994. Research and cumulative watershed effects. USDA Forest Service, Pacific Southwest Station, Albany, CA. PSW-GTR-141. 118p.

Robertson, F. D. 1992. Ecosystem management of the national forests and grasslands. Memo to Regional Foresters and Station Directors, USDA Forest Service, Washington, D.C. June 4, 1992.

Rosgen, David L. 1994. A classification of natural rivers. Catena 22(3):169-199.

Smith, R. D. 1992. A conceptual framework for assessing the functions of wetlands. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS. Technical Report TR-WRP-DE-3.

Society for Range Management. 1995. Evaluating rangeland sustainability: the evolving technology. Rangelands 17(3):85-92.

USDA Forest Service. 1992. Ecology based multiple-use management. USDA Forest Service, Southwestern Region. 5p.

USDA Forest Service. 1993. Integrated resource management: The road to ecosystem management. USDA Forest Service, Southwestern Region. 28p.

Zonneveld, I. S. 1983. Principles of bio-indication. Environmental Monitoring and Assessments 3:207-217.

Ecological condition of the East Fork of the Gila River and selected tributaries: Gila National Forest, New Mexico

Robert D. Ohmart[1]

Abstract.—Ecological condition of riparian habitats along the East Fork of the Gila River, Main Diamond Creek, lower South Diamond Creek, and Black Canyon Creek are all in very heavily degraded condition. Channel cross-sections show extensive entrenchment, high width-to-depth ratios, and numerous reaches where banks are sloughing into the stream, especially on the East Fork of the Gila River. Species of floodplain vegetation typifies degraded channel conditions. Absence of woody species disallows bank stabilization except where entrenched to large cobble. Data from channel cross-sections and vegetation sampling validate these conditions.

Numerous anthropogenic factors have been involved in the degradation of these riparian systems to their current condition, but the major degrading force has been unmanaged domestic livestock grazing either season-long or year long. Potential to recover these fluvial systems to proper functioning condition is high with management intervention. Stream gradients are moderate to low and sediment loads sufficient for bank formation. All stream reaches are in wilderness areas.

Wildlife values of these habitats are presently very low because of the heavily degraded stream channel, poor herbaceous ground cover, and the virtual absence of understory and canopy foliage layers. Historically, these were habitats for the endangered Gila trout (*Oncorhynchus gilae*) and southwestern willow flycatcher (*Empidonax traillii extimus*).

INTRODUCTION

In the arid Southwest, riparian habitats represent <1% of the landscape yet their importance in water quality, as fish habitat, and for wildlife far outweighs that of any other habitat (Minckley 1973, Carothers et al. 1974). When streams are in Proper Functioning Condition (PFC; Bureau of Land Management 1993), they provide maximum water quality values as well as optimum fish and wildlife habitat. Though many agents are responsible for riparian habitat degradation in the Southwest, the Arizona Comparative Environmental Risk Project listed groundwater pumping, domestic livestock grazing, and water management activities as being the three major stressors to these systems (Patten and Ohmart 1995). Numerous endangered species occur in these habitats and more are in the process of being listed (Horning 1994).

Unmanaged domestic livestock grazing has been extremely degrading to riparian systems because it has been practiced for 100+ years and is generally ubiquitous (Ohmart ms). The initial phase of stream and channel degradation is obvious and rapid, while later phases of degradation are subtle and slow. Riparian habitat deterioration is not apparent to the casual observer and only

[1] *Professor of Zoology, Center for Environmental Studies, Arizona State University, Tempe, AZ.*

becomes obvious through data collection or with repeat photography.

This paper presents data on stream channel condition and vegetative distribution on a reach of the East Fork of the Gila River on the Gila National Forest in New Mexico. The 12 km of stream reach on the East Fork is a riparian pasture where livestock numbers and time of use should be easily managed. Stream gradient is moderate (0.06%) and the relatively wide floodplain is contained by vertical canyon walls. The watershed for the East Fork is approximately 2,626 km^2. The gauging station is above Gila, New Mexico, and combines flows for the West, Middle, and East forks of the Gila. The recorded 2-yr discharge (bankful discharge) is 1,800 ft3/sec (cfs). Flows _1,800 cfs occur predominately in December-March and August-October (Thomas and Dunne 1981). Winter rainfall patterns are generally widespread so records are probably representative of the combined three forks. Summer/fall rainfall events are usually very localized, so gauged flows may vary from rainfall in a portion of a fork to a combination of all three.

METHODS

Vegetation data were collected on channel cross-sections 1, 3, 4, 5, 7, 9, 10, 12, and 16. This report contains data from cross-section 3. Vegetation transects were superimposed on hydrologic cross-sections, i.e., they were perpendicular to the water flow, but vegetation transects usually extended more laterally than cross-sections to span the width of the floodplain (pediment to pediment).

Plant communities along transects were based on dominant plants in each plant community. Plant communities were mapped as well as the location of plant communities along the transect. Locations of boundaries between, for example, the floodplain and the terrace were also noted. Photographs of major plant communities were taken.

Cover estimates were made inside 1 m^2 plots. Estimates were made of percent cover of each plant species and of nonvegetative cover. Plots were located at the water's edge, at the near-stream edge of the highest terrace, and about halfway across the highest terrace, on both sides of the river, for a total (normally) of 6. Each plot was photographed.

Photographs were taken to characterize the reach containing each transect. On each bank, there were 11 photographic locations about 30 m apart, including 1 location where the transect crossed the stream, 5 locations upstream, and 5 locations downstream. At each location, a photograph was taken across the stream and another downstream. In addition, at the location farthest upstream, one photograph for each transect was taken upstream. The total number of reach photographs for each transect was 45.

Photographic data is with Susan Schock of GilaWatch, Silver City, New Mexico. Other data, including plant specimens, is at the Center for Environmental Studies, Arizona State University, Tempe, Arizona.

RESULTS

The floodplain was subdivided into 13 segments from left to right along the cross-section (fig. 1). Each segment represents an area either where there was major topographic or vegetational change across the floodplain. In figure 1 it can be seen that the river (old channel) had moved toward the left pediment about 26Êm. The left bank is a high gravel bar and supports scattered nonriparian plant species. The right bank and segments up to and including the old channel are presently the primary floodplain and of the 26 species in these segments, 22 are riparian plant species.

Channel incisement has lowered the water table across the floodplain, consequently, second terraces (two leftmost segments and three rightmost segments) seldom receive overbank watering and groundwater table recharge except in large flood events. Of the 20 species occurring in these segments only 6 were riparian species. Vine mesquite (*Panicum obtusum*) occurred as a relict producing occasional seed heads. Willows (*Salix* spp.) reached their maximum densities in the outermost segments near the mountain pediments where soil moisture levels are maintained by surface runoff. Numerous upland species have invaded these segments.

Riparian species were present in these segments, but their abundance was low (table 1), especially the woody element *Salix* spp. At the right edge of water only 50% of the area supported these riparian species. *Cyperus* sp. dominated the area with

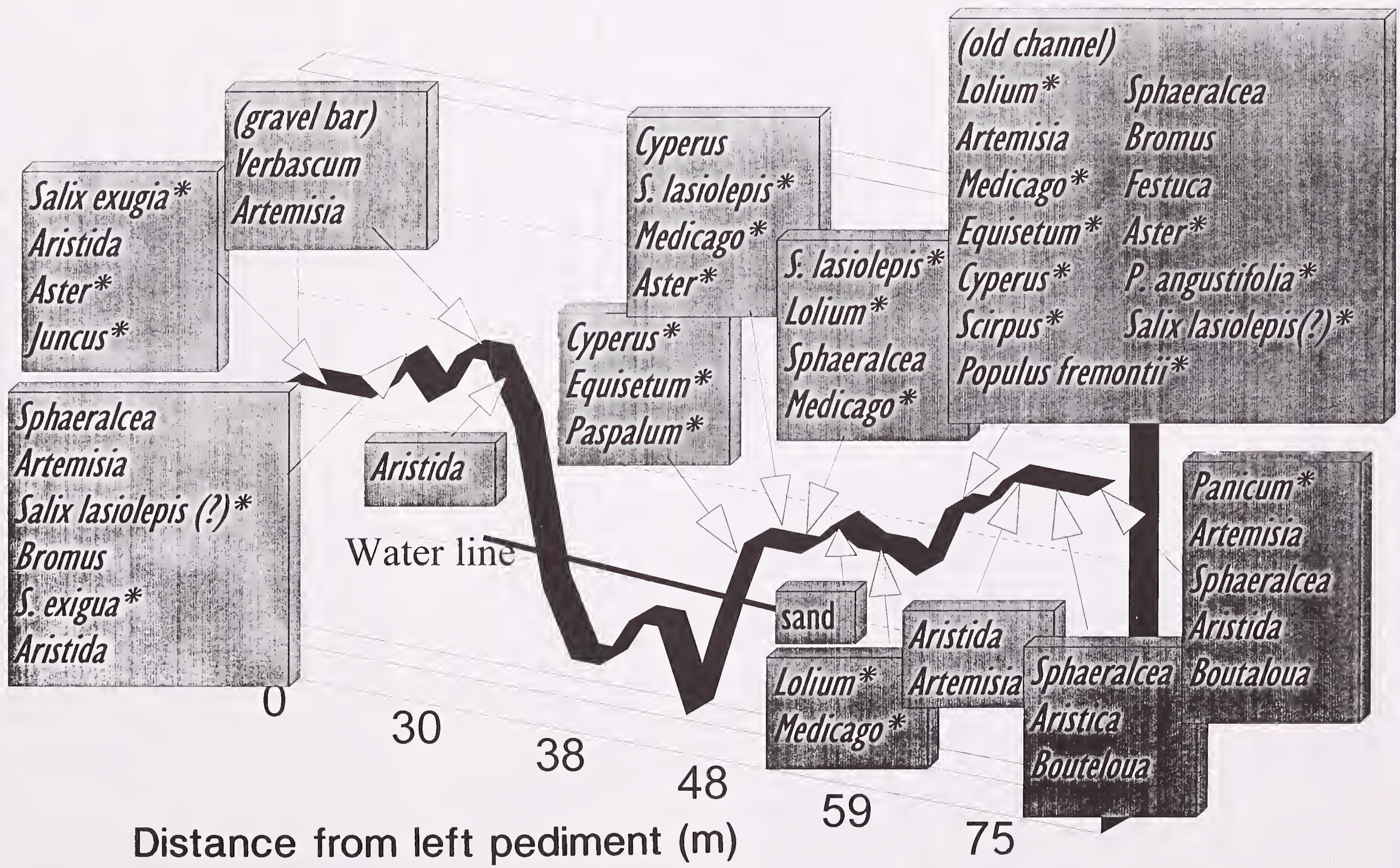


Figure 1. Plant species distribution along a cross-section of the East Fork of the Gila River, Gila National Forest, New Mexico.

Table 1. Location of vegetation, cover type, and percent cover by species on a cross-section on the East Fork of the Gila River, Gila National Forest, New Mexico.

LOCATION	COVER TYPE	% COVER	PLANT SPECIES	% COVER
Right edge of water	Vegetation	50	*Cyperus**	90
	Litter	45	*Paspalum**	1
	Water	5	*Equisetum**	9
Right edge of highest terrace	Vegetation	98	*Aster**	10
	Litter	2	*Medicago**	15
			*Equisetum**	1
			*Paspalum**	10
			Festuca	5
			Muhlenbergia	10
			Sphaeralcea	5
			*Salix**	3
Right, ½ across terrace	Vegetation	20	*Eriogonum*	5
	Nonvegetation	80	*Panicum**	2
			Yellow composite	3
			Unknown seedling	1
			Aristida	10
Left edge = edge of highest terrace	Soil	5	*Aristida*	95
	Litter	2	*Aster**	1
			Sphaeralcea	1
			*Equisetum**	1
Left edge, ½ across terrace	Soil	5	*Aristida*	88
	Litter	3	*Salix**	15
	Vegetation	92	*Artemisia*	3
			*Cyperus**	1
			Bromus	1
*Indicates			*Rumex*	1
riparian species			*Sphaeralcea*	1

90% cover along with *Equisetum* sp. and knotgrass (*Paspalum distichum*) being only 1%. Along the right floodplain halfway across the terrace there was 20% vegetative cover with vine mesquite covering only 2% of the floodplain. The left floodplain halfway across supported the highest amount of vegetation (92() with *Aristida* sp. dominating (88%) and *Salix* sp. covering 15%. Most of the species were from the upland habitat.

DISCUSSION

The major tributaries of the East Fork of the Gila River discussed in this paper are Main Diamond, South Diamond, and Upper Black Canyon creeks. I have hiked some of the other tributaries, but my experience and field notes are more complete on the above streams. The logistics of visiting streams on the Gila and Aldo Leopold wilderness areas requires extensive amounts of time and hiking to visit and collect data.

The East Fork of the Gila River is in a highly degraded state primarily because of 100+ years of unmanaged livestock grazing. Its ecological condition fits the three phases of western stream degradation (Ohmart ms) and is a Phase III where the collapse of the mature cottonwood (*Populus* spp.)-willow association has occurred. Scattered mature and decadent narrow-leafed (*P. angustifolia*) and Fremont (*P. fremontii*) cottonwoods persist, but the gallery forest no longer exists. Small, young populations of willows and cottonwoods occasionally occur along the floodplain, but these are primarily located adjacent to the mountain pediments where livestock seldom forage. There are sparse, scattered stands of larger trees (20-30 yrs of age) which appear to be from a 10-yr period when stocking rates were much lighter over the allotment.

This portion of the Gila River is a riparian pasture and the past stocking rate has been 70 bulls during the nongrowing season. My observations of these animals grazing habitats show them using primarily 3 m on either side of the river. During the past 5 yrs I have hiked total or partial reaches of this stream at least 10 times in the growing season. Trespass cattle numbers have ranged from a minimum of 4 up to 27 head, again their primary grazing activity being concentrated along the stream edges.

Though knotgrass occurs relatively abundant along many stream edges along with scattered sedges (*Carex* spp., *Cyperus* spp.) and rushes (*Juncus* spp.) these species alone are incapable of preventing bank erosion during flood events. Without the woody root mix of willows floodwaters are too erosive (Beschta and Platts 1986, Clifton 1989, Elmore 1992). Very few willow stems can be observed along the stream edge and those that appear are quickly browsed back.

The significant reduction and loss of riparian vegetation along the tributaries and the East Fork of the Gila River are similar to what Jackson (1994) reported in the Zuni Mountains on the Cibola National Forest in New Mexico. He estimated a 70 to 90% reduction in riparian vegetation as streams entrenched and water tables dropped thus narrowing the active floodplain and riparian vegetation. Domestic livestock were involved along with other stressors such as logging and roads. An area that once supported 10,000 head now has 1,000 animals grazing it (Jackson 1994). Riparian habitat losses on the East Fork of the Gila River are 95% or more.

It could be argued that elk (*Cervus elaphus*) and cattle are both contributing to the problems of overutilization along the floodplain. Occasional elk pellet groups were observed along the floodplain, but the preponderance of the fecal material is domestic livestock. Along South Diamond Creek, a tributary of the East Fork, scat counts in belt transects show a ratio of 4 elk to 100 cattle.

This stream reach was once important habitat for the endangered Gila trout (*Oncorhynchos gilae*) and willow flycatcher (*Empidonax traillii extimus*). Unmanaged livestock grazing has reduced it to a warm-water fishery with high sediment loads and virtually no shade (U.S. Forest Service 1995). With 8-10 yrs of rest and the planting of willow slips along the water's edge, the area could provide valuable habitat for these endangered species, quality recreational experiences, and some livestock forage.

Water quality data (U.S. Forest Service 1995) show that the state standard of 10 nepholometric turbidity units (NTU) were exceeded by 17 NTUs on the upper end of the riparian pasture on the East Fork and by 19 NTUs on the lower end of the 12 km reach. Sediment standards were also exceeded by 1.5 NTUs on Diamond Creek where it exits the allotment. Data on microinvertebrates, which compared existing conditions to expected, showed community structure and composition

(species richness) to be impaired on the East Fork of the Gila River above the confluence with Diamond Creek (U.S. Forest Service 1995).

The above data combined with shade estimates of 0-5% (U.S. Forest Service 1995) for the East Fork demonstrate why this stream reach is no longer suitable habitat for Gila trout. Trout, as a group, require clean, cold water with trees and shrubs providing 70% shade from 10 AM to 4 PM for optimum habitat conditions (Armour 1978, Bowers et al. 1979, Oregon-Washington Interagency Wildlife Committee 1979, Reiser and Bjornn 1979). Trees and shrubs not only provide shade to prevent solar heating of the water, but 99% of the energy in the stream comes from exogenous sources (Borman and Likens 1969, Likens and Borman 1974), such as leaves and twigs of the vegetation along the stream channel. The woody roots of these trees and shrubs combined with the fibrous roots of the herbaceous vegetation stabilize banks and create overhanging banks for further shade and hiding cover for trout.

Present conditions of the East Fork with a wide, shallow channel characterized by sloughing banks with no woody vegetation demonstrate why this stream is now a warm-water fisheries and no longer suitable for native trout. Small populations of this trout persisted in the small headwaters of Main Diamond and South Diamond creeks, but these populations have been recently extirpated because of ash from fires on the watersheds. Upper Black Canyon Creek is a larger headwater stream than Main or South Diamond creeks, but its degraded condition is worse than the East Fork and unsuitable for trout. Willows have been virtually extirpated and the cottonwood forest is down and dead along Upper Black Canyon.

LITERATURE CITED

Armour, C. L. 1978. Effects of deteriorated range streams on trout. U.S. Department of the Interior, Bur. Land Manage., Idaho State Office, Boise ID. 7.

Beschta, R. L.; Platts, W. S. 1986. Morphological features of small streams: significance and function. Water Resources Bulletin. 22(3):369-379.

Borman, F. H.; G. E. Likens. 1969. The watershed-ecosystem concept and studies of nutrient cycles. *In* V. Dyne, ed. The ecosystem concept natural resource management. Academic Press, New York, N.Y.

Bowers, W.; Hosford, B.; Oakley, A.; Bond, C. 1979. Wildlife habitats in managed rangelands — the Great Basin of southeastern Oregon: native trout. U.S. For. Serv. Gen. Tech. Rep. PNW-84. 16.

Carothers, S. W.; Johnson, R. R.; Aitchison, S. W.. 1974. Population structure and social organization of southwestern riparian birds. American Zoologist 14:97-108.

Clifton, C. 1989. Effects of vegetation and land use on channel morphology. In: Practical approaches to riparian resource management: an educational workshop. Bur. Land Manage., Billings, MT.121-129.

Elmore, W. 1992. Riparian responses to grazing practices. In: Watershed management: balancing sustainability and environmental change. Springer-Verlag, New York, NY.

Horning, J. 1994. Grazing to extinction: endangered, threatened and candidate species imperiled by livestock grazing on western public lands. Washington, D.C.: National Wildlife Federation.

Jackson, F. 1994. Documenting channel condition in New Mexico. Stream Notes: Special Summer Issue 1994.

Likens, G. E.; Borman, F. H. 1974. Linkages between terrestrial and aquatic ecosystems. Bioscience 24:447-456.

Minckley, W. L. 1973. Fishes of Arizona. Arizona Game and Fish Department, Phoenix, AZ.

Oregon-Washington Interagency Wildlife Committee. 1979. Managing riparian ecosystems (zones) for fish and wildlife in eastern Oregon and eastern Washington. Riparian Habitat Subcomm. Oregon/Washington Interagency Wildl. Comm., Portland, OR. March 1979. 44.

Patten, D. T.; Ohmart, R. D. 1995. Riparian ecosystems. In: Arizona Comparative Environmental Risk Project, Section 2, Ecosystems. U.S. Environmental Protection Agency, Arizona Department of Environmental Quality, and the Commission on the Arizona Environment.

Reiser, D. W.; Bjornn, T. C. 1979. Habitat requirements of anadromous salmonids. U.S. For. Serv. Gen. Tech. Rpt. PNW-96. 54.

Thomas, R. P.; Dunne, A. 1981. Summary of basin and flood characteristics for unregulated basins in New Mexico. U.S. Geological Survey Open-File Rpt. 81-1071.

U.S. Forest Service. 1995. Environmental Impact Statement: Diamond Bar Allotment Management Plan. Grant, Sierra, and Catron Counties, New Mexico. Gila National Forest, Silver City, NM.

Channel bed particle size distribution procedure used to evaluate watershed cumulative effects for range permit re-issuance on the Santa Fe National Forest

Bruce Sims[1], Jim Piatt[2], Lee Johnson[3], Carol Purchase[4], and John Phillips[5]

Abstract.—Personnel on the Santa Fe National Forest used methodologies adapted from Bevenger and King (1995) to collect base line particle size data on streams within grazing allotments currently scheduled for permit reissuance. This information was used to determine the relative current health of the watersheds as well as being used in the development of potential alternatives to current grazing practices, where deemed necessary.

INTRODUCTION

Two recent studies (Bevenger and King, 1995 and Potyondy and Hardy, 1994) have documented the successful use of channel bed particle size distribution as an indicator of watershed health. These studies adapted the Wolman pebble count methodology (Wolman, 1954) to study the effects of wildfire, timber harvest, and livestock grazing. Channels with higher percentages of fine particle sizes are considered more disturbed or impacted.

Personnel on the Santa Fe National Forest used methodologies adapted from Bevenger and King (1995) to collect base line particle size data on streams within grazing allotments currently scheduled for permit reissuance. This information was used to determine the relative current health of the watersheds as well as being used in the development of potential alternatives to current grazing practices, where deemed necessary.

[1] *Forest Hydrologist, Santa Fe National Forest.*

[2] *Bureau Chief, Surface Water Quality Bureau, New Mexico Environment Department.*

[3] *Range, Wildlife and Timber Staff, Pecos/Las Vegas District, Santa Fe National Forest.*

[4] *Hydrologist, Flathead National Forest.*

[5] *Range Conservationist, Jemez District, Santa Fe National Forest.*

BACKGROUND

Considerable scientific literature exists regarding the effects of grazing on riparian and aquatic habitats. In 1982, William Platts (1982) presented a paper in which he reviewed 20 studies by fishery specialists. All but one study concluded that riparian-stream habitats had been degraded by livestock grazing (Platts, 1982). Grazing has been found to be the major contributor to surface water pollution in the State of New Mexico (NM Water Quality Control Commission, 1994).

Channel substrate has been found to be an important factor affecting microhabitat. Fine sediment in excessive amounts can change the structure of aquatic communities, reduce primary productivity, and reducing the suitable spawning areas for coldwater fish (Winget and Mangum, 1979, McNeil and Ahnell 1964, and Cooper 1965). The State of New Mexico has designated all of the streams and rivers on the Santa Fe National Forest as coldwater fisheries (NM Water Quality Control Commission, 1995). Because spawning of coldwater species in New Mexico is only successful over clean gravels (Sublette, Hatch and Sublette, 1990), protection of the channel substrate from excessive anthropogenic inputs of soil sized particles is necessary to protect this resource.

Streams adjacent to heavily grazed sites have been found to have higher percentages of fines (i.e., soil size particles less than 2 millimeters in diameter) and correspondingly lower percentages of gravels, cobbles, and boulders (Lusby, 1970). Thus, it was deemed to be necessary to develop and implement a monitoring program to determine the current health of these waters prior to reissuance of new grazing permits.

METHODS

To assess the effects of cattle grazing on selected streams on the Santa Fe National Forest, a field procedure for characterizing particle size distributions was adapted from methodologies developed by Bevenger and King *op. cit.*. Bevenger and King modified the Wolman procedure, which randomly sampled bed material within a grid system, by using a zigzag pattern, progressing from one side of the active channel to the edge of the other side.

In our analysis the particle directly under the tip of the right boot was measured on every other step. To avoid a possibility of sampler bias in particle collection, we decided that the sampler must consistently pick up the first particle felt at the boot tip. The intermediate diameter (i.e., neither the longest nor shortest axis) was then measured with a ruler and noted using Wentworth size notation form (Figure 1). Using the Wentworth size notation methodology, all particles less than two millimeters in diameter were classed as fines. At least 100 samples were collected on all streams sampled. Sample locations were noted and marked on the ground so that changes in particle size distribution could be monitored through time.

Figure 1. Wentworth particle size classes.

STUDY SITES, MONITORING, AND RESULTS

Measurements were made on forty streams on the Santa Fe National Forest during the 1995 field season. In this paper we discuss results from several streams that we feel show the strengths and weaknesses of this technique. To determine if pebble count distribution provided results which were useful and could be explained, cursory watershed condition evaluations were done for each study site.

Particle size data analysis indicated a wide range of variability between streams (Figure 2). This was expected as natural variables such as volume of flow, channel geometry, channel slope, geology and soil types could affect the measured distribution as could many land management practices, such as grazing, within the watershed. Fine particle sizes ranged from almost 39 percent to only one percent with an average of 14.7 percent. Similarly, significant variability was noted in the total gravel fraction (maximum - 90%, minimum - 35%, average - 67%), cobble fraction (maximum - 51%, minimum - 8%, average - 28.4%) and boulder (maximum - 18%, minimum - 0%, average - 4.7%). However, when two adjacent watersheds with

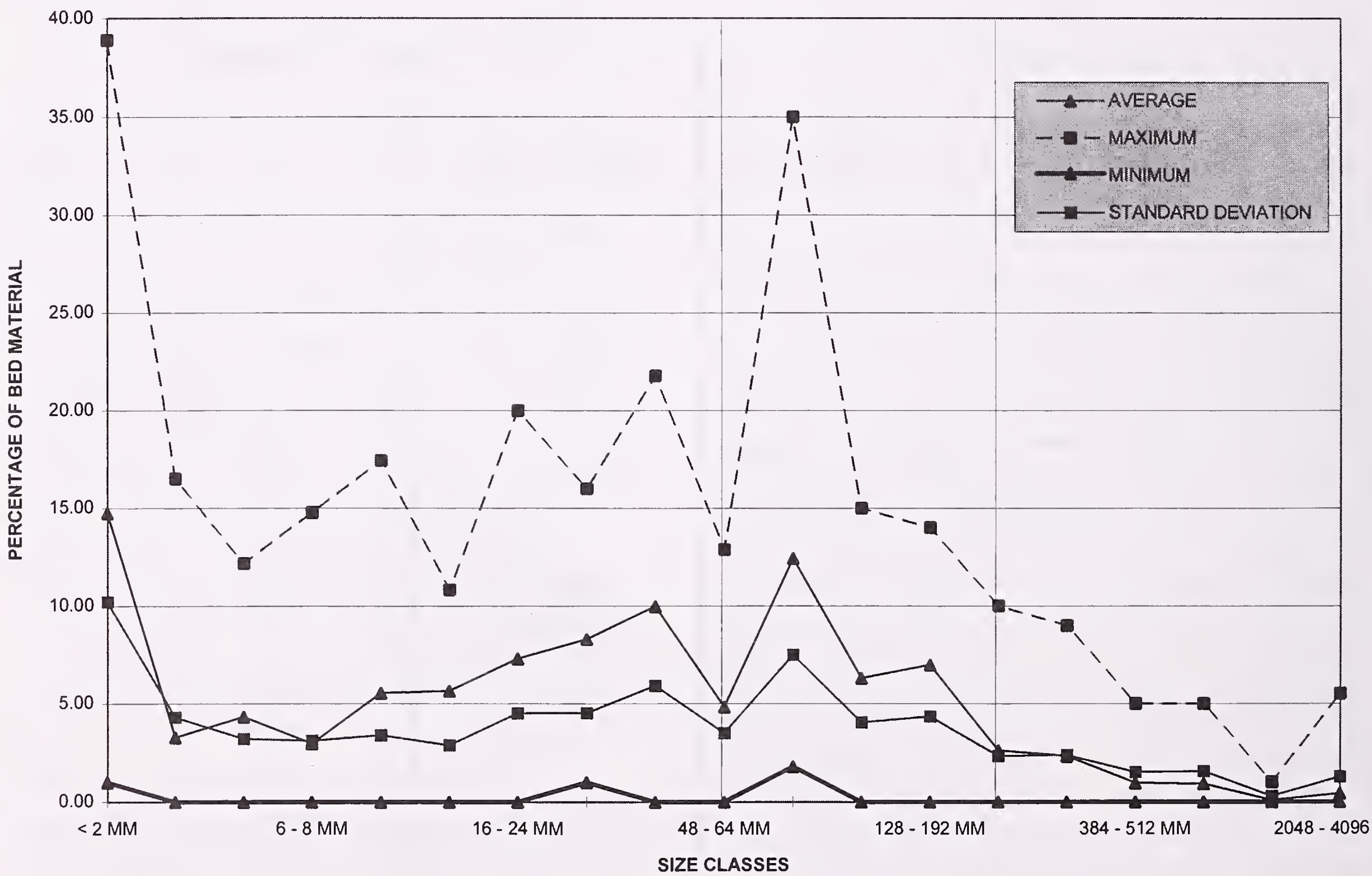


Figure 2. Descriptive statistics: Percentage composition by particle size class.

similar natural features and land use are compared, particle size distribution is very similar (Figure 3). This figure shows a cumulative plot of channel bed particle size distribution for Tecolote and Blue Canyon Creeks located in the Sangre de Cristo Mountains southwest of Las Vegas, New Mexico.

When an upstream particle size distribution is compared against a downstream distribution, in the largely undisturbed Tecolote Watershed (Figure 4), we note that the upstream station exhibits a larger percentage of smaller gravel sized particles even when the percentage of fines is essentially identical. In that channel gradient and geology are unchanged from the upstream sample point, we believe that this result is probably due to increased stream power as the watershed becomes larger.

In a disturbed watershed, the particle size distribution changes very differently in a downstream direction (Figure 5). The Vallecitos Creek Watershed located southeast of Jemez Springs in the Jemez Mountains contains a high road density, and unsurfaced roads parallel the stream for miles. The percentage of fine particles at the downstream sample point is approximately 300 percent higher than that found at the upstream sample site. Percentages of cobbles and boulders are similar at

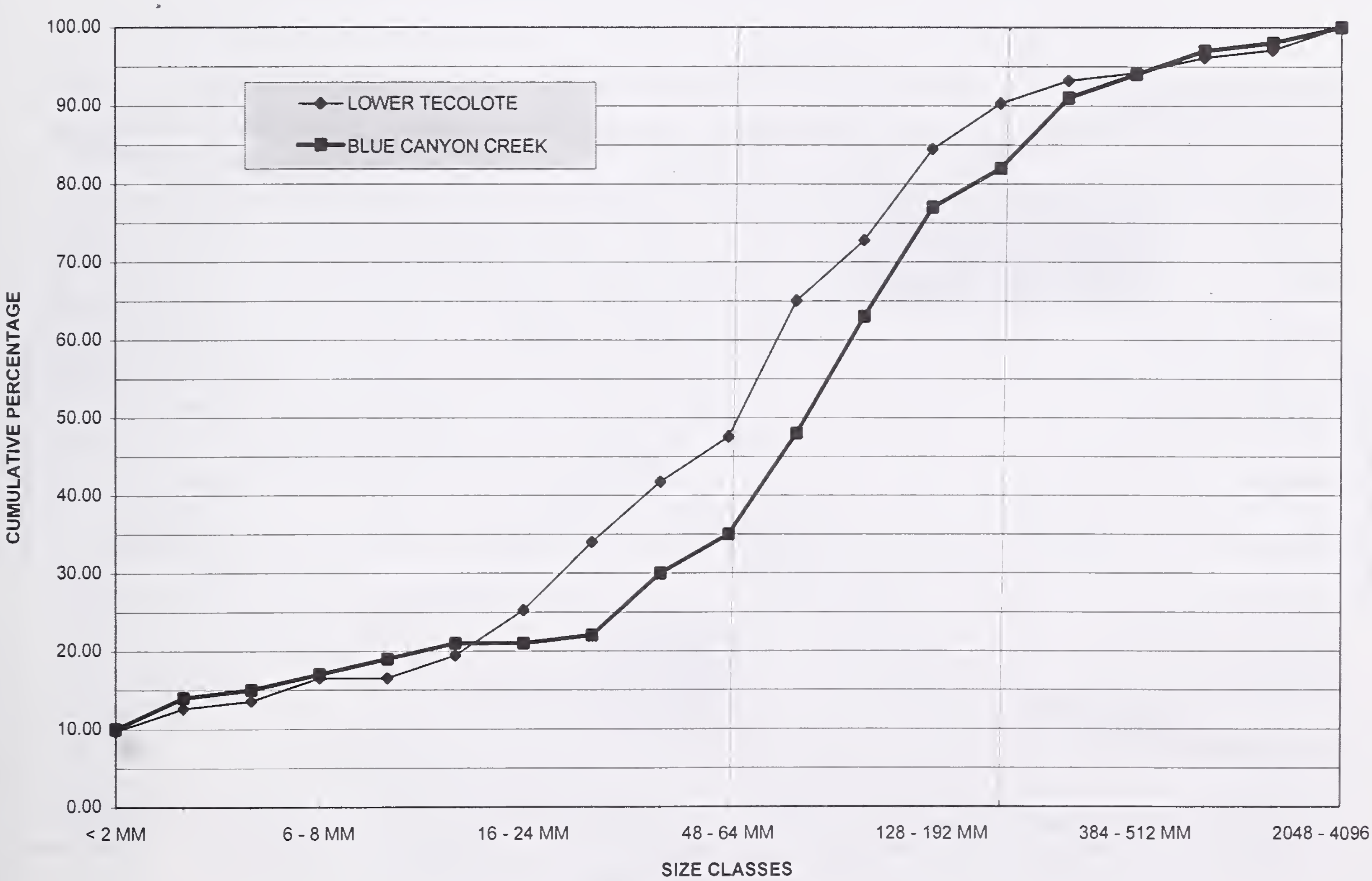


Figure 3. Comparison of particle size distribution of Tecolote Creek with its largest tributary.

both sites. Though channel gradient and geology are similar at both locations, the road that parallels the stream has been closed and seeded in the location of the upper sample site reducing input of fines to that portion of the stream.

In a second disturbed watershed, the East Fork of the Jemez River, we found very different conditions and results (Figure 6). The upstream station was located just below private lands and showed higher concentrations of fines than did a downstream station (10 percent vs 3 percent). The private land upstream is intensively grazed and streams and their attendant riparian areas are not protected. Though the downstream site located on National Forest land is also grazed and receive heavy recreation use, the relative effects of these activities on fine particles percentages appear to be less.

Single sample points on disturbed watersheds can help quantify observed watershed conditions (Figure 7). On San Pablo Creek located in the Nacimiento Mountains southeast of Cuba, New Mexico, eroding roads drain directly into the stream at several locations. A particle size distribution sample was taken downstream of such an eroding road. This sample showed that 30 percent

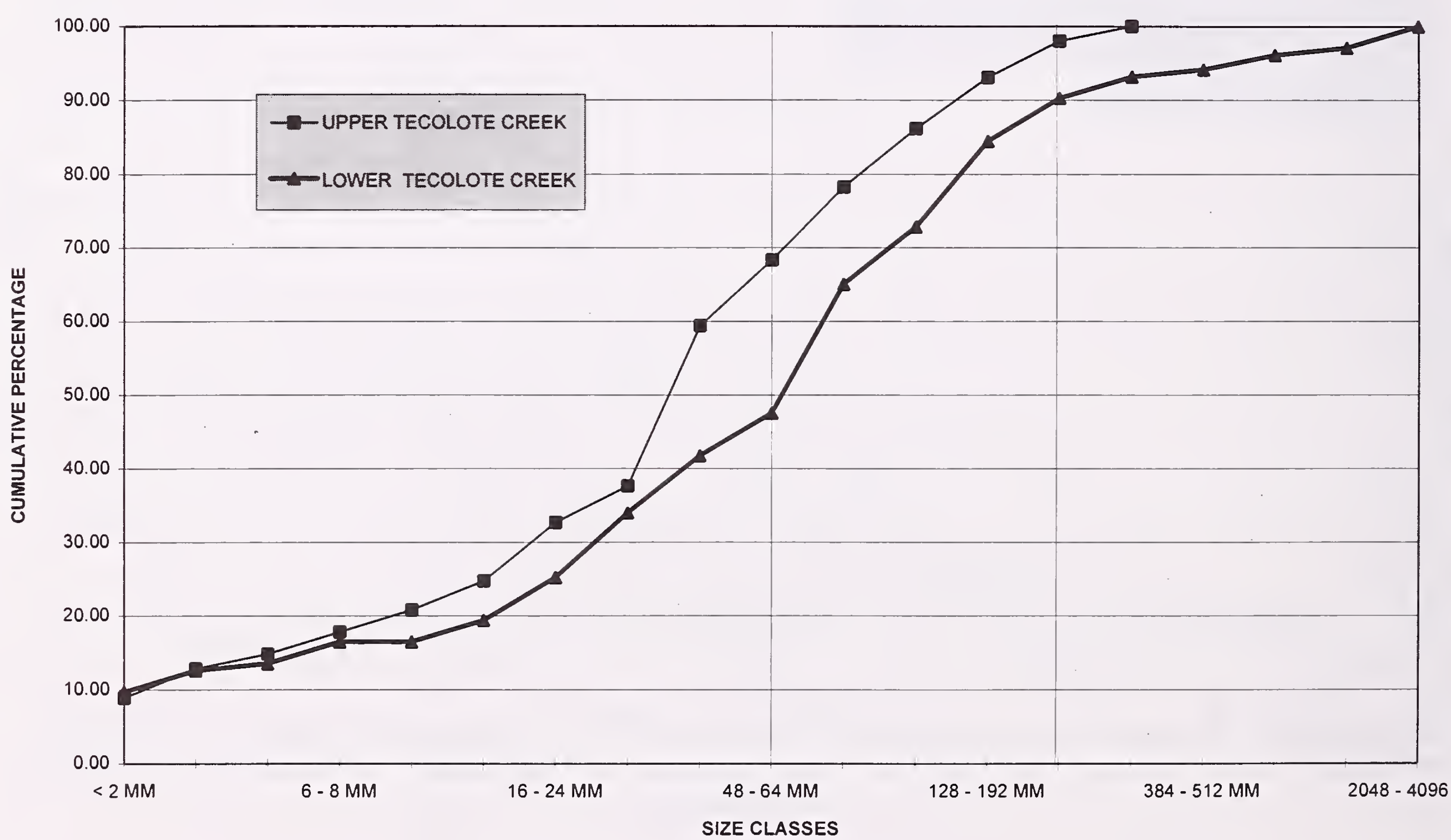


Figure 4. Comparison of particle size distributions at stations on Tecolote Creek.

of the channel bed particles were fines less than 2 mm in diameter. This was well in excess of the Forest average of about 15 percent fines found during our investigations. We anticipate that once road drainage problems are corrected the percent of fines within the channel bed will decrease through time, and that this decrease could be easily documented with this technique.

A single sample was also taken along San Jose Creek located northeast of Cuba, New Mexico (Figure 8). The headwaters of this stream are located in the San Pedro Parks Wilderness. This stream appears to have incised during the first half of the Twentieth Century probably as a result of overgrazing. Improvement in range management in the past few years has greatly improved headwater riparian conditions. Today, though incised, riparian vegetation is dense, and particle size distribution showed a very low percentage of fines. However, because of the absence of accessible flood plain in many stream reaches, a large magnitude flood is expected to create sufficient water velocities in the confined channel to damage riparian vegetation and reactivate active channel erosion. This example illustrates the importance of using a trained observer to evaluate the condition of the watershed as well

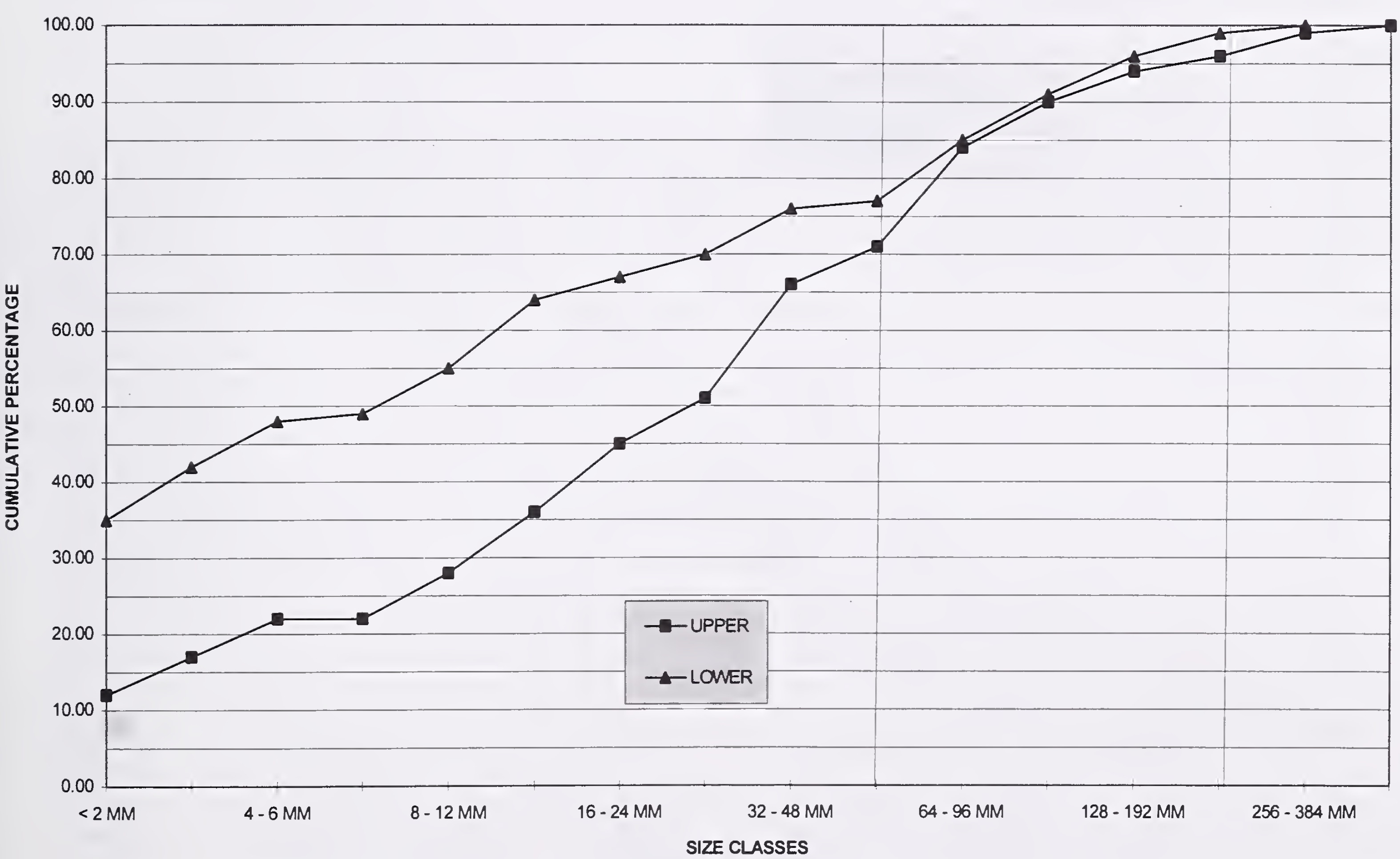


Figure 5. Comparison of particle size distributions at stations on Vallecitos Creek.

as a need to temper temptation to judge watershed condition based solely on a statistical basis.

DISCUSSION AND CONCLUSIONS

We believe particle size distribution is a powerful cost-effective landscape evaluation and monitoring tool. Just as physicians can use a human blood test to indicate a medical problem, watershed scientists can use particle size distribution patterns to indicate watersheds that are out of adjustment. Both tests likewise can be used for long-term monitoring. Like any other tool it must be used by skilled individuals trained to evaluate watershed conditions but should not be considered to be the only evaluative tool necessary. Such monitoring will not allow us, for example, to determine the presence of chemical pollutants which may be of concern.

The method was found to produce consistent results when compared across similar watersheds. Results from streams whose watersheds had known management concerns clearly demonstrated the movement of fines into the aquatic environment. Yet, in watersheds with only limited anthropogenic impacts and uniform geology,

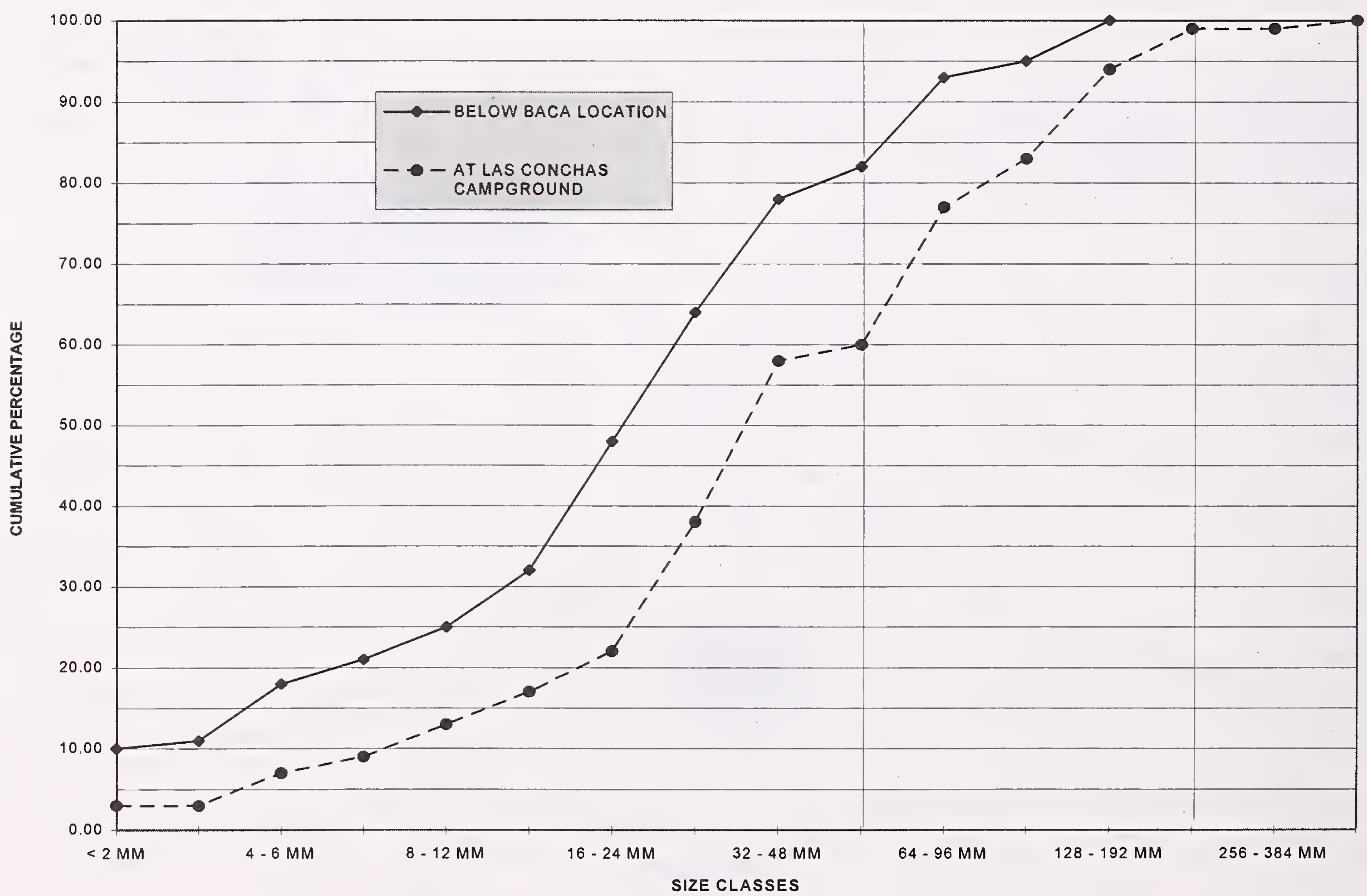


Figure 6. Comparison of particle size distribution at stations on the East Fork of the Jemez River.

results were also able to document hydrologic phenomena such as increases in flow.

Potyondy and Hardy *op. cit.* found increases in fine particle-size percentage following high magnitude disturbances of wildfire and dam breaks. Our data suggest that lower magnitude watershed disturbances such as uncontrolled road drainage or overgrazing along a stream can be quantified using particle size distribution.

BIBLIOGRAPHY

Bevenger, Gregory S. and Rudy M. King, 1995. A Pebble Count Procedure for Assessing Watershed Cumulative Effects. USDA Forest Service Research Paper RM-RP-319, Fort Collins, CO, 17 pp.

Cooper, O.B., Ed. 1979. Proceedings, Forum—Grazing and Riparian/Stream Ecosystems. Trout Unlimited Inc., Washington, D.C., 94 pp.

Lusby, G. 1970. Hydrologic and Biotic Effects of Grazing vs. Nongrazing Near Grand Junction, Colorado. J. Range Management. 23(4):256-260.

New Mexico Water Quality Control Commission, 1994. Water Quality and Water Pollution Control in New Mexico 1994. NMED/SWQ-94/4. 243 pp. + Appendices.

New Mexico Water Quality Control Commission, 1995. State of New Mexico Standards for Interstate and Intrastate Streams. 20 NMAC 6.1

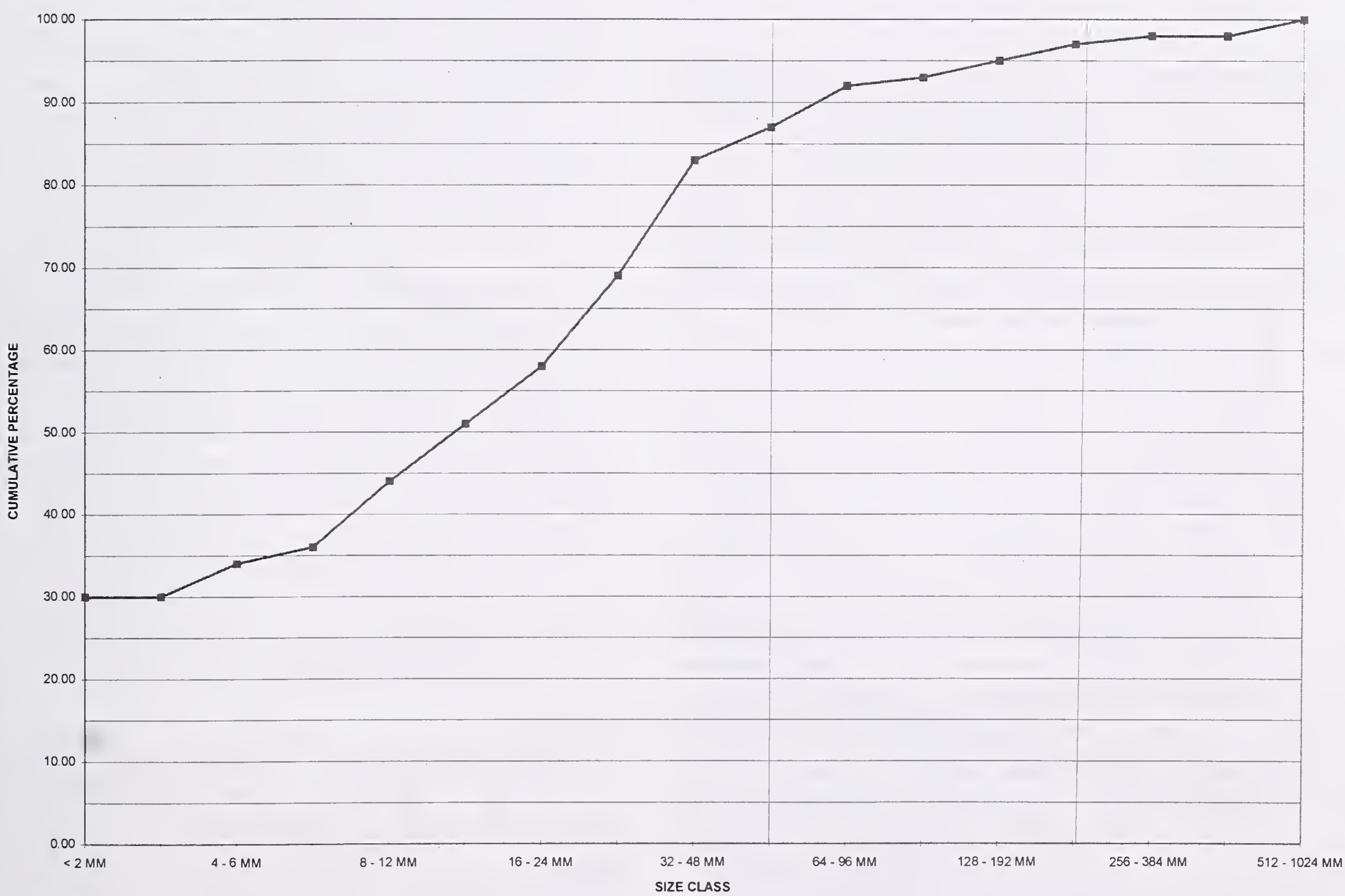


Figure 7. Particle size distributin at San Pablo Creek.

Platts, William S. 1982. Livestock and Riparian-Fishery Interactions: What Are the Facts? Transactions of the Forty-seventh North American Wildlife and Natural Resources Conference, March 26-31, Portland, OR.:507-515.

Potyondy, J.P. and T. Hardy, 1994. Use of Pebble Counts to Evaluate Fine Sediment Increase in Stream Channels. Water Resources Bulletin. 30(3):509-520.

Sublette, J.E., M.D. Hatch and M. Sublette. 1990. The fishes of New Mexico. University of New Mexico Press. 393 pp.

Winget, Robert N. and Fred A. Mangum, 1979. Biotic Condition Index: Integrated Biological, Physical, and Chemical Stream Parameters for Management. USDA Contract No. 40-84M8-8-524, Provo, Utah., 51 pp.

Wolman, M.G. 1954. A Method of Sampling Coarse River-bed Material. Transactions American Geophysical Union 35(6):951-956.

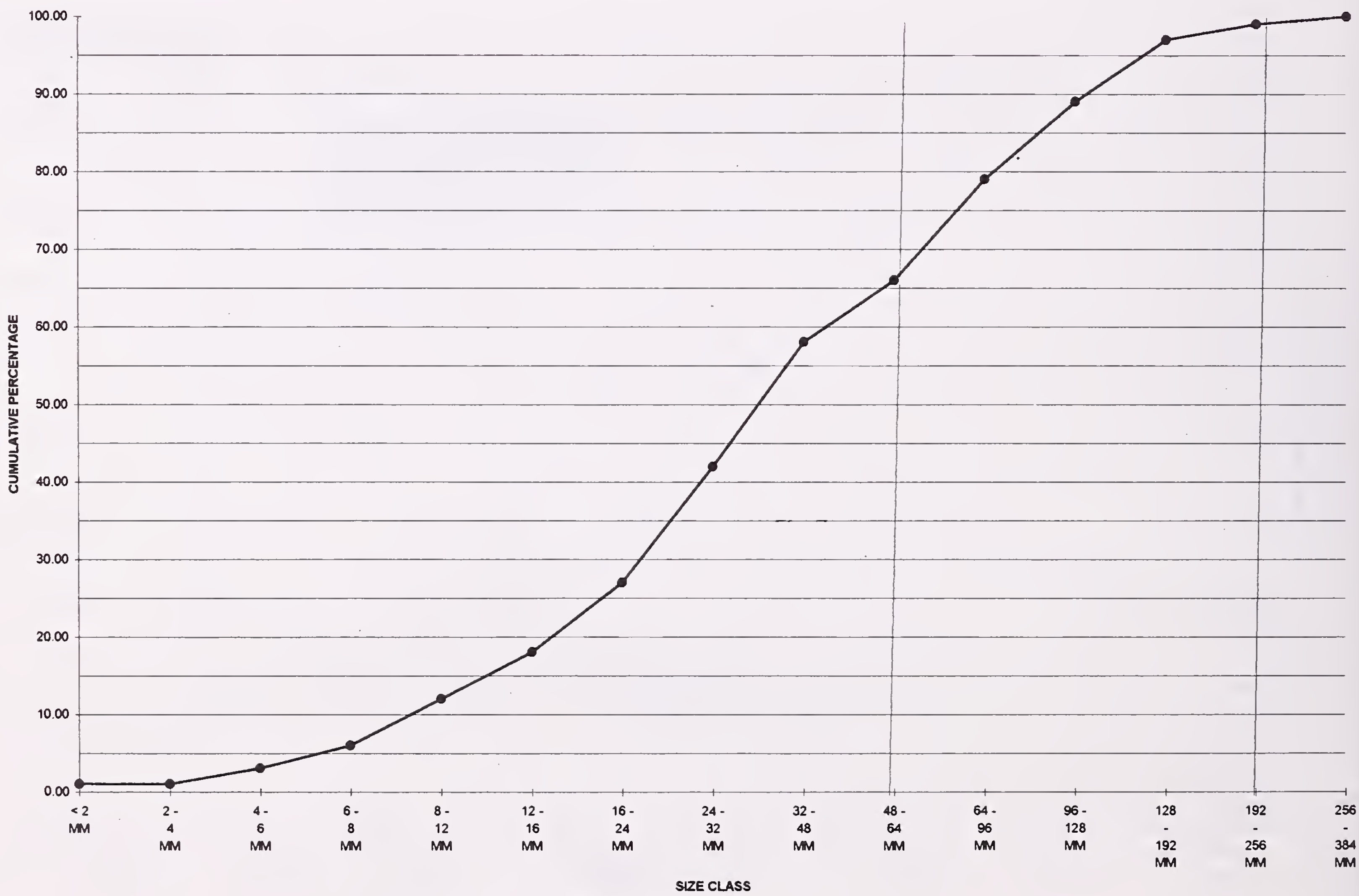


Figure 8. Particle size distribution at San Jose Creek.

GIS applications in riparian management

Carrie Christman[1], Douglas W. Shaw[2], Charles L. Spann[3] and Penny Luehring[4]

Abstract.—GIS was used to prioritize watersheds for treatment needs across the USDA Forest Service Southwestern Region. Factors in this analysis included soil condition, riparian habitat, population centers and mining sites.

Hydrologic units, or watersheds, are a basic subdivision of the ecological hierarchy for Ecosystem Management utilized by the USDA Forest Service (McNab and Avers 1994). To determine appropriate management strategies for each watershed, it is critical to have information about the condition of the watershed as influenced by environmental factors and management activities. GIS (Geographic Information System) was used in this study to compile information about various factors affecting watershed condition and to analyze their cumulative impact on the watershed. The desired outcome of the study is to rank each of the Southwestern Region's 11-digit hydrologic units for priority for treatment.

This study was initiated by conducting an information needs assessment to determine the digital map layers needed to perform the analysis in GIS. The list of map layers identified as important included: 11-digit hydrologic units, USDA Forest Service General Ecosystem Survey (GES), mine locations, areas of significant human population, threatened and endangered species habitat, water quality data, and road locations. A survey of data availability was conducted to determine which of these data layers could be obtained within a time frame to be included in the initial analysis.

The data layers that were both available and readily useable within an ARC/INFO GIS, included 11-digit hydrologic units, General Ecosystem Survey, mine locations and population centers. State-wide coverages of 11-digit hydrologic units were obtained from the Arizona and the New Mexico offices of the Natural Resources Conservation Service (NRCS). The General Ecosystem Survey divides the Southwestern Region into mapping units based on soil, water, and vegetation components. These mapping units were delineated at the 1:250000 scale by the USDA Forest Service. GES contains information about soil condition and riparian areas. The mine location data was derived from the Mineral Industry Location System managed by the U.S. Bureau of Mines. Data for Arizona cities with populations greater than 5,000 came from the Arizona State Land Department's Arizona Land Resources Information System. The cities data for New Mexico came from the New Mexico's Resource Geographic Information System Program.

Data identified in the information needs assessment that were not readily available for this study included roads, threatened and endangered species habitat, and water quality. A region-wide coverage of roads is not yet available in digital format. Electronic versions of seven and one-half minute quadrangle maps are available for most of the Southwestern Region. These digital maps only contain a portion of the total number of roads that actually exist on the ground. A comprehensive road layer is needed to calculate road densities within watersheds.

The threatened and endangered species habitat locations exist in the U.S. Fish and Wildlife's Heritage tabular database, but not as GIS layers.

[1] *Spatial Database Specialist, Southwestern Region, USDA Forest Service, Albuquerque.*

[2] *Program Planning and Budget Coordinator, Southwestern Region, USDA Forest Service, Albuquerque.*

[3] *Water Resource Program Manager, Southwestern Region, USDA Forest Service, Albuquerque.*

[4] *Soil Resource Program Manager, Southwestern Region, USDA Forest Service, Albuquerque.*

The Forest Service has region-wide locations for Mexican Spotted Owl habitat, but not for other species. Water quality data for Arizona have been mapped. Water quality data for New Mexico exist only in tabular and narrative format.

The geographic extent of the GES data set constrained the analysis because the data for soil condition and riparian areas exist only for areas within Forest Service boundaries. The analysis looks at management problems of entire watersheds, but these data sets were limited to only the Forest Service portion of each watershed.

Map layers received from various sources did not come "ready to use". It needed to be converted into a format useable by ARC/INFO. The map coverages needed to be reprojected into a geographic projection identical to the rest of the data sets. Some data needed to be edited and attributed before it was useful within the design of this analysis.

After each data set was edited and converted to a common format and geographical projection, initial maps of each data layer were produced. This visual display helped to determine the appropriate model for the study. The Regional Hydrologist developed the following model:

Rank = (NFS acres/total acres) +
(unsat. soils/NFS acres) +
(riparian/NFS acres) +
(Municip. > 5K) + mines

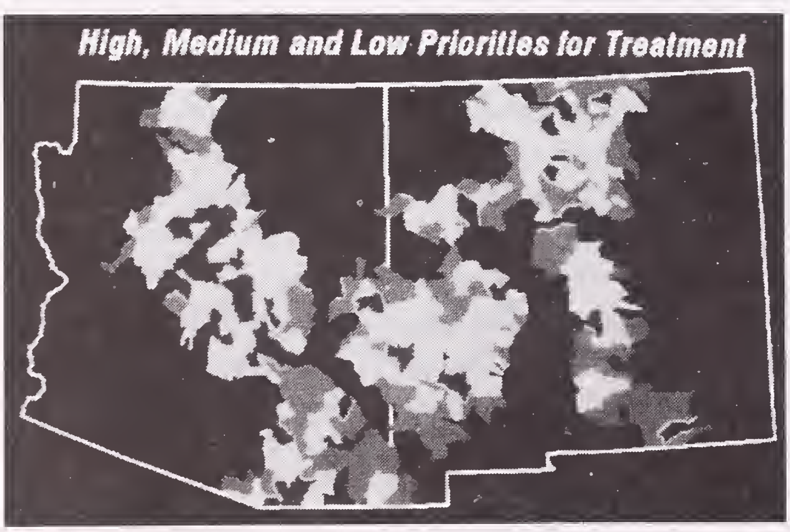


Figure 1. High, medium, and low priorities for watershed treatment.

This translates for each watershed as the ratio of National Forest Service (NFS) acres to total acreage of the watershed, plus the ratio of acres of unsatisfactory soils to NFS acres, plus the ratio of riparian acres to NFS acres, plus (yes or no) the presence of a municipality over 5,000 in population, plus the number of mine sites. Each resulting ratio was assigned a weighting factor. The presence of a municipality over 5,000 population was given a weighting factor, and weighting factors were assigned according to the number of mine locations.

To calculate the ratios in the model, each data layer had to be merged with the watershed layer. The cities and the mine location data had statewide extents. These layers were clipped to the watershed boundaries. Ratios calculated for each factor were broken out into categories by percent and assigned a weighting factor. The five factors, forest acres, unsatisfactory soils, riparian areas, cities and mines were summed for each watershed and a ranking was assigned. Calculations to produce the rankings were performed within the INFO database of ARC/INFO. Initial tabular results and corresponding maps were produced and reviewed by the authors.

The rankings were checked against the maps. The mine location data that was used covered the full extent of the watersheds, not just Forest Service Land. This appeared to give too much weighting to mine locations over other factors in the equation. The analysis was repeated, with the mine data clipped to Forest Service Land. Final tabular results and a final map were produced. The map showed high, medium, and low priority watersheds. The distribution of the data appeared to be normal, with the greatest number of watersheds receiving a medium priority ranking. The authors concluded that GIS is a useful tool for the prioritization of watersheds. The study will be more valuable as additional information becomes available for GIS and is included in further analyses.

LITERATURE CITED

McNab, W. Henry; and Avers, Peter E. 1994. Ecological Subregions of the United States: Section Descriptions. Ecosystem Management. United States Department of Agriculture. Forest Service. Washington, D.C.

Native aquatic plants and ecological condition of southwestern wetlands and riparian areas

Alvin L. Medina[1]

Abstract.—The determination of the ecological condition of wetland and riparian habitats has been the focus of research by many scientists, because of the importance to understand the processes and related functions of these systems. Research on montane wetland and riparian systems has shown the relative importance of native aquatic plants in maintaining these systems in a functional condition. The presence or absence of key species is used as an indicator of the ecological condition, and desired ecological condition of wetlands and riparian habitats can be expressed in terms of the species composition and abundance of native aquatic plants. This type of information is needed by resource managers in defining the endpoint of their management actions. Information is presented on the functional role of these species in sustaining the biological and physical integrity of these habitats.

INTRODUCTION

Wetland and riparian habitats of the Southwest are extremely valuable natural resources. These areas are very productive owing to their capacity to produce:

- High volumes of forage for herbivores,
- Good water quality, and
- A diverse flora and fauna.

Unfortunately, most of these habitats are in a degraded condition as a result of natural events (e.g. floods, fires), man-induced activities (e.g. roads, recreation), and animal-induced activities (e.g. grazing, trampling). Many restoration tactics have been tried over the past 75 years, including reseeding, structural stream improvements, modified livestock grazing systems, and exclusion from grazing. Unfortunately these efforts produced limited results because the symptoms were treated, rather than the causes. In most cases the primary cause of degradation of riparian and wetland areas is loss of the native aquatic flora.

Despite the extensive distribution of *Carex* and *Juncus* species in riparian meadows and wetlands of the Southwestern United States, there is a great lack of information and understanding of the role these plants play in maintaining healthy, functional ecosystems. *Carex* wetlands in parts of the Old World, such as Iceland have been managed for forages for at least 1,000 years (Ingvason 1969). Herein I discuss the value and function of a selected group of native aquatic species of Southwestern riparian and wetland habitats, namely species of the genera *Carex*, and *Juncus*, and how such species contribute to the enhancement and sustainability of a desirable functional condition. A list of species found on fully functional (near pristine) habitats is presented and used as a basis for assessing the ecological condition of other habitats. In addition, key species for use in restoration are suggested. Results presented are taken from riparian research being conducted on the Apache-Sitgreaves National Forest (A/S NF) and Coconino National Forest.

[1] *Research Ecologist, USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Flagstaff, AZ.*

FUNCTIONAL CONDITIONS

For purposes of clarity 'desirable functional conditions' are defined as being a set of habitat conditions that are exhibited on an ecosystem, such as a riparian or wetland site. The goal is not to define the ecological status, e.g. succession, or channel type, but rather the condition of the habitat, since riparian and wetland ecosystems are capable of being functional at any ecological status. A comprehensive description of desirable functional processes is provided in Medina et al. (this issue).

CHARACTERISTICS OF A FUNCTIONAL RIPARIAN ECOSYSTEM

1. **Stable streambanks -** As defined by their capacity to withstand repeated hydrologic events without significant loss of bank material, owing to their inherent geological character and the presence of vegetation. Alluvial systems characterized by cobble, gravels and sands, are by nature unstable even with the presence of vegetation, whereas streambanks whose soils are high in organic matter, silts and clays are generally more stable, provided they support the right kind of vegetation.
2. **Good water quality** - As defined by the acceptable limits to sustain desirable habitat conditions for flora and fauna.
3. **High water table -** As defined by the distance from the top of streambank to the base level of the water table, and the presence of native aquic or mesic type plants on the streambank and floodplain.
4. **High biomass production -** As defined by the potential of the site to permit plants to grow at or near their full potential. The native aquatic graminoids nearly always produce greater biomass than other graminoids.
5. **Assimilation of organic matter into the soil -** As defined by the percent organic fraction present in diagnostic soil horizons. Organic matter acts as a binding agent for the cohesion of soil particles.
6. **Perennial vegetation -** As defined by species composition. Perennial plants, especially native aquatic graminoids, have extensive, strongly fibrous root systems that protect the soil surfaces and matrix from the erosive forces of water, trampling, etc.
7. **Native vegetation -** As defined by the class of species that are endemic to the area.
8. **Sustained aquatic fauna -** As defined by the continued presence and relative abundance of organisms.
9. **Soil matrix -** Longterm storage and retention of soil moisture to promote perennial flows.

VALUE OF NATIVE AQUATIC PLANTS

Various scientists and resource managers have expounded on the multiple benefits that can be derived from wetland and riparian habitats (Daniel et al. 1979, Rodiek 1980, Johnson and Carothers 1982, USEPA 1988, Fry et al. 1994, Richardson 1994, Zube and Sheehan 1994), including hydrologic concerns (Carter 1986), economics (Crandall 1992), recreation (Johnson and Carothers 1982), and grazing (Behnke 1978). Considerable information has also been provided through symposia (Johnson and McCormick 1978, Johnson et al. 1985, Mutz Lee 1987, Tellman et al. 1993). However, there is very little specific information on such aspects as productivity and functional values of specific plants.

Native aquatic plants are of primary importance in sustaining desirable functional processes (Medina et al., this issue), particularly those that affect channel stability. Most bank instability problems result from the cumulative and interactive effects of loss of streambank vegetation, hydrologic phenomena, and continued ungulate use. Hence, a single most important function of a riparian or wetland plant is to maintain the functional stability (Medina et al. this issue) of the stream channel or shore, such that degradation is limited. Many scientists have reviewed the literature and reported on these factors (Skovlin 1984, Platts and Raleigh 1984, Kauffman and Krueger 1984, Platts 1990).

In a survey of similar channel types of 12 streams in Arizona conducted between 1992 and 1995, it was found that streams with little to no

plant cover of native *Carex* species were in a highly degraded condition (or dysfunctional), while streams that exhibited a high degree of bank stability, herbage production, and functionality (Medina et al. this issue) had streambanks dominated with a variety of native *Carex* species (Table 1). Ord Creek exhibited all the traits of a fully functional riparian/wetland habitat despite its high runoff, elk grazing, and granitic substrates. The most obvious factors that explain this ecological condition are the type and amount of native *Carex* species. Streams which had Kentucky bluegrass (*Poa pratensis*), orchardgrass (*Dactylis glomerata*), wheatgrasses (*Agropyron* spp.), bromes (*Bromus* spp.), and other seeded graminoids as the dominant species occupying the streambanks exhibited signs of degradation, such as sloughing, downcutting or entrenchment, channel widening, and lowering of the water table. Costello (1944) reported that Kentucky bluegrass had effectively replaced native plant species and was an indicator of moderately heavy grazing in wet meadows. This observation holds true today on most Southwestern riparian meadows. Streams with lowered water tables tend towards more mesic conditions in adjacent meadows, which in turn favor exotic grasses (Kauffman et al. 1983).

Another important value of native aquatic plants is their high herbage production. Results of herbage production studies on 2 similar riparian areas on the Colorado Plateau for 3 consecutive years show that the production potential of riparian habitats ranges from about 2,830 kg ha^{-1} for sites rested from ungulate grazing for one season (Wildcat Creek on A/S NF), to an average of 4,315 kg ha^{-1} (Buck Springs on Coconino NF) on sites rested for 4 years (Medina, unpublished data). Roath (1979) reported herbage production on some Oregon riparian meadows between 2,268 to 2,675 kg ha^{-1}. Reece et al. (1994) reported average yields from 3,870 kg ha^{-1} in June to 6,090 kg ha^{-1} in August for a Nebraska Sandhills wet meadow. Gorham and Somers (1973) estimate yields from sedge meadows to be between 2,000 kg ha^{-1} in sub-arctic, and montane sites to almost 15,000 kg ha^{-1} in a lowland mid-latitude site. In contrast, yields of Kentucky bluegrass of 1,000 kg ha^{-1} have been reported for dense swales by Wiegert and Evans (1964). Bernard (1974) compared peak yields of Kentucky bluegrass and *Carex rostrata* to be 1,140 kg ha^{-1} and 8,520 kg ha^{-1}, respectively. Manning et al. (1989) demonstrated that root biomass of kentucky bluegrass was 7 times less than *Carex nebraskensis* in the upper 0-10 cm soil depth and more than 300 times less in the 10-20 cm depth. The production of large quantities of herbage translates to greater forage availability for livestock and wildlife, plus the added advantage of having greater above ground biomass available during bank-full flow events to improve water infiltration, retention, and storage, and to capture and retain greater amounts of suspended sediments and nutrients.

Table 1. Comparison of streambank stability by streams as a function of the percent of exotic plant cover for a 3000 m reach.

Stream	% Exotic vegetation	% Stable banks
Boggy Creek, A/S NF	64	31
Buck Springs, Coconino NF	71	29
Centerfire Creek, A/S NF	82	11
E. Clear Creek, Coconino NF	69	34
Houston Draw, Coconino NF	67	22
Fern Mountain, Coconino NF	83	16
McKnight Creek, Gila NF	88	7
Merritt Creek, Coconino NF	32	78
Ord Creek, White Mtns, AZ	3	98
Reservation Creek, White Mtns, AZ	17	85
W. Fork Black River, A/S NF	81	27
Wildcat Creek, A/S NF	29	84

DYNAMICS OF CAREX AND OTHER AQUATIC PLANTS

The following discussion is based on current research of the interactions among aquatic vegetation, ungulates, channel hydrology, and geomorphic processes in montane riparian ecosystems. Given the lack of information about processes that govern such interactions, I submit for consideration this (yet) theoretical description of streamside dynamics based on practical field experiences and published research.

Determination of the ecological condition of selected riparian habitats is difficult when the sites in question are degraded or dysfunctional. Consider the case of a typical Southwestern stream

reach whose meadows have been exposed to impacts from grazing, logging, roads and recreation. This stream reach could exhibit such characteristics as having a channel type of C, F, or possibly even a G (as per Rosgen 1994), with Kentucky bluegrass/wheatgrasses as the dominant vegetation, and a low or decreasing water table. In all likelihood, the ecological potential of this reach is an E-type channel (for gradients <2%), with streambanks dominated with species of *Carex, Juncus, Eleocharis, Scirpus, Glyceria,* and a high water table that sustains sedges, rushes, and other aquatic vegetation. How did such a system changed from the latter to the former? How can this system be restored to a functional state that would approximate the latter conditions?

Through the combined effects of man and animal induced activities the reach became degraded, unproductive and subject to erosion. Early (1920's-1950's) efforts promoted the restoration of these habitats by reseeding, most often with highly adaptable exotic species such as Kentucky bluegrass. In more recent times (1950's-1980's) other species such as orchard grass, assorted wheatgrasses and bromes were reseeded. These reseeded species fare well when the system is in a declining condition. They are highly suited to the mesic conditions brought about by the decreasing water table, which in turn is a product of channel erosional processes resulting in downward and lateral channel migration with each major storm event (Heede 1981, 1992). Sedges became scarce owing to grazing and associated channel dynamics. Reseeded species and other ruderal species replaced sedges and rushes on streambanks. These mesic species generally have a shallow and fine root system in contrast to the long, thick and fibrous roots of sedges (Bernard and Gorham 1978, Manning et al. 1989). Plants native to wetlands and streambanks are mostly water-loving species capable of withstanding prolonged periods of alternating wet and dry conditions (Rumburg and Sawyer 1965), an advantageous life strategy that most mesic graminoids lack. Continued ungulate trampling and general overuse of the habitat also leads to compaction problems, since large masses of surface roots of sedges, in contrast to minuscule quantities of mesic species roots (Manning et al. 1989), function to keep bulk densities low (Moore and Rhoades 1966).

The hydrologic interactions with the streambank vegetation is complex but close examination over time reveals the deficiencies of reseeded and exotic species to stabilize streambanks (Smith 1976, Heede 1985). Hence, at some point in time the stream reach can be described as follows:

1. F channel type characterized by impoverished vegetation and near vertical streambanks,
2. Low water table (perhaps at bedrock),
3. Poor water quality owing to high suspended sediments,
4. Reduced herbage production resulting from lower water table and disturbance adapted vegetation,
5. Low fishery quality (loss of habitat and fauna),
6. Carcasses of woody plants, and
7. In a general state of hydraulic disequilibrium (Heede 1992).

Despite these negative conditions, there can most often be found a microsite at the water's edge where sedges and rushes have prevailed and are working to restore the site to a functional state accordingly. This natural restoration process begins through the continued expansion of the sedges and rushes interacting with flow events which erode and deposit sediments about the new floodplain being developed. Expansion is generally slow owing to the clonal nature of the genera (Carlsson and Callaghan 1990, Wikberg et al. 1994). Sediment deposits about the sedges provide a source of nutrients for growth (Aerts and Caluwe 1994). This physical depositional process interacts with the (biological) plants collectively to produce a geomorphologically distinct micro-landscape form which most often is recognized as point bars, which generally mark the onset of the restoration of the physical parameters of the system to a higher functional state. The continued interactions between physical processes of degradation and aggradation, and the biological component (i.e. vegetation) eventually may result in a C-type channel (Rosgen 1994) if the system if protected from further disturbance. Geomorphological development generally takes place within the confines of channel carve out while still in a F-type, such that the C-type eventually reaches the

original E-type, but maybe within an entirely different confinement.

It is hypothesized that the rate of recovery is a function of the rate of re-establishment of the sedges and rushes, sediment deposition, and flow conditions. Sediments and bank-full flows are essential for building streambanks, but the vegetation is most essential for the geomorphological development of channel types (Heede 1985). Many other inter- and intra- component interactions between physical, biological, and chemical factors occur, and which yet remain to be described. One such interaction involves plant competition dynamics in which the native aquatic species displace the exotic mesic species, especially under protection from grazing (Kauffman et al. 1983).

IMPORTANT NATIVE AQUATIC PLANTS

There are several species that have been observed to be essential in the restoration of streambanks of montane riparian or wetland habitats of the Southwest and are also representative of habitats in excellent ecological condition. The distribution of any given species on a riparian or wetland is certainly not uniform since many species are clonal and may be specific to wetter or drier microsite conditions. Some scientists suggest that nutrient limitations may be important in the distribution of sedge meadows (Auclair 1982, Bernard an Fiala 1986). Many other species are known to occur (Reed 1988) but have not been observed in our plant studies or are not considered key species for restoration. The list is preliminary, and a more comprehensive list of flora found on habitats with excellent ecological condition is forthcoming.

The principal sedge species are water sedge (*Carex aquatilis*), slender-beak (*C. athrostachya*), wooly (*C. lanuginosa*), *C. lenticularis*, Nebraska (*C. nebraskensis*), pointed broom (*C. scoparia*), and stalk-grain (*C. Stipata*). Rushes also are a major component of the flora and include Baltic rush (*Juncus balticus*), soft rush (*J. effusus*), long-style (*J. longistylis*), Rocky Mountain (*J. saximontanus*), slender (*J. tenuis*), iris-leaf (*J. xiphioides*). Baltic rush is the common species on wetlands and riparian meadows reaches with standing water yearlong. Small-fruit bulrush (*Scirpus microcarpus*) is another species that is common on sites where streambank building is occurring. Many grasses are also found in varying proportions, but spreading bentgrass (*Agrostis stolonifera*) is the most common associate with sedges and rushes.

Plants that are frequently associated with the re-establishment of a new streambank, particularly in a F-type channel, are wooly and stalk-grain sedges. These tall growing (40-60 cm) plants produce large amounts of biomass which aids in the trapping of bank sloughed materials and suspended sediments. It is not uncommon to find creeping spikerush (*Eleocharis palustris*) as the pioneer species and associated with these sedges.

Nebraska sedge is another key species that pervades riparian meadows and streambanks where the water table is high. This plant has a high root length density nearly 12 times greater than Kentucky bluegrass (Manning et al 1989), can withstand high degrees of defoliation with little apparent damage (Ratliff 1983, Ratliff and Westfall 1987) and produce high quantities (>2500 kg ha^{-1}) of forage, and is one the few species identified that colonize within riffles and stabilize streambanks (Medina, unpublished data).

DESIRED FUTURE CONDITION AND SEDGES

Sedges are a vital biological component of any riparian or wetland ecosystem. Their role in sustaining the dynamic equilibrium of the stream system has only recently be recognized by scientists and resource managers. The proper functioning of a riparian or wetland system is highly dependent on the composition, abundance and health of these types of plants. Collectively, these plants produce an effect over time on the stream channel through the interactions of soil, water and vegetation dynamics that results in stable streambanks. Streambank stability is vital to the sustainability of the stream ecosystem. An aquatic system that is functioning at or near its potential will also have such conditions as desirable habitat for fish and other aquatic fauna and flora, high biomass productivity, and high water table. Sedges, or native aquatic graminoids collectively, are a very important biological component that interact with its environment to produce a desir-

able functional condition. The presence or absence of key species is used as an indicator of the ecological condition, and desired ecological condition of wetlands and riparian habitats can be expressed in terms of the species composition and abundance of native aquatic plants.

LITERATURE CITED

Aerts, R. and H. De Caluwe. 1994. Nitrogen use efficiency of *Carex* species in relation to nitrogen supply. Ecology 75:2362-2372.

Auclair, A.N.D. 1982. Seasonal dynamics of nutrients in a *Carex* meadow. Can. J. Bot. 60:1671-1678.

Behnke, R.J. 1978. Grazing and the riparian zone: impact on aquatic values. In Lowland rover and stream habitat in Colorado, A Symposium, Oct. 4-5, 1978. Greeley, CO. University of N. Colo., Colo. Audubon Council, Soil Conserv. Soc., and Bur. Land Manage. pp126-132.

Bernard, J.M. 1974. Seasonal changes in standing crop and primary production in a sedge wetland and an adjacent dry old-field in central Minnesota. Ecology 55:350-359.

Bernard, J.M. and E. Gorham. 1978. Life history aspects of primary production in sedge wetlands. In R.G. Good, D.F. Whigham and R.L. Simpson (Eds.), Freshwater Wetlands: Ecological processes and management potential. Academic Press, Inc., N.Y. pp-39-51.

Bernard, J.M. and K. Fiala. 1986. Distribution and standing crop of living and dead roots in three wetland *Carex* species. Bull. Torrey Bot. Club 113:1-5.

Carlsson, B. A. and T.V. Callaghan. 1990. Programmed tiller differentiation, intraclonal density regulation and nutrient dynamics in *Carex bigelowii*. Oikos 58:219-230.

Carter, V. 1986. An overview of the hydrologic concerns related to wetlands in the United States. Can. J. Bot. 64:364-374.

Costello, D.F. 1944. Important species of the major forage types in Colorado and Wyoming. Ecol. Monogr. 14:106-134.

Crandall, K.B. 1992. Measuring the economic values of riparian areas: a case study. Arid Lands Newsletter 32:18-21.

Daniel, T.C., E.H. Zube and B.L. Driver. 1979. Assessing amenity resource values. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. Gen. Tech. Rep. RM-68, this issue.

Fry, J. F. Steiner and D. Green. 1994. Riparian evaluation and site assessment in Arizona. Landscape and Urban Plan. 28:179-199.

Gorham, E. and M.G. Somers. 1973. Seasonal changes in the standing crop of two montane sedges. Can. J. Bot. 51:1097-1108.

Heede, B. H. 1981. Dynamics of selected mountain streams in the western United States of America. Zeitschrift fur Geomorphologie N.F. 25:17-32.

Heede, B. H. 1985. Interactions between streamside vegetation and stream dynamics. In Riparian ecosystems and their management: Reconciling conflicting uses, Tucson, AZ.pp54-58.

Heede, B.H. 1992. Stream dynamics: an overview for land managers. USDA Forest Service, Washington, D.C. Gen. Tech. Rep. WO-12.

Ingvason, P.A. 1969. The golden sedges of Iceland. World Crops 21:218-220.

Johnson R.R. and J.F. McCormick (tech. coords.). 1978. Strategies for protection and management of floodplain wetlands and other riparian ecosystems. USDA Forest Service, Washington, D.C. Gen. Tech. Rep. WO-12.

Johnson R.R. and S.W. Carothers (tech. coords.). 1982. Riparian habitats and recreation: interrelationships and impacts in the Southwest and Rocky Mountain region. Eisenhower Consort. Bull 12. 31p.

Johnson R.R., C.D. Ziebell, D.R. Patton, P.F. Ffolliott and R.H. Hamre (tech. coords.). 1985. Riparian ecosystems and their management: Reconciling conflicting uses. Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. USDA Forest Service, Washington, D.C. Gen. Tech. Rep. RM-120.

Kauffman, J.B., W.C. Krueger, and M. Vavra. 1983. Effects of late season cattle grazing on riparian plant communities. J. Range Manage. 36:685-691.

Kauffman, J.B. and W.C. Krueger. 1984. Livestock impacts on riparian plant communities and streamside management implications, a review. J. Range Manage. 37(5):430-437.

Manning, M.E., S.R. Swanson, T. Svejar and J. Trent. 1989. Rooting characteristics of four intermountain meadow community types. J. Range Manage. 42:309-312.

Medina, A.L., M.B. Baker, Jr., and D.G. Neary. 1996. Desirable functional processes: a conceptual approach for evaluating ecological condition. In Proceedings of the Riparian Symposium on Desired Future Conditions for Southwestern Riparian Ecosystems. Albuquerque, New Mexico. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, this issue.

Moore, A.W. and H.F. Rhoades. 1966. Soil conditions and root distribution in two wet meadows of the Nebraska Sandhills. Agron. J. 58:563-566.

Mutz, K. and L.C. Lee (tech. coords.). 1987. Wetland and riparian ecosystems of the American West. In Eighth Ann. Meet. Soc. Wetland Scientists, May 26-29, 1987, Seattle, WA. 349p.

Neary, D.G., and Medina, A.L. 1996. Geomorphological response of a montane riparian habitat to interactions of ungulates, vegetation and hydrology. In Proceedings of the Riparian Symposium on Desired Future Conditions for Southwestern Riparian Ecosystems. Albuquerque, New Mexico. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, this issue.

Platts, W.S. and R.F. Raleigh. 1984. Impacts of grazing on wetlands and riparian habitat. In National Research Council/National Academy of Sciences report on Developing Strategies for Rangeland Management. Westview Press, Boulder, CO. pp 1105-1118.

Platts, W.S. 1990. Managing fisheries and wildlife on rangelands grazed by livestock: A guidance and reference document for biologists. Unpublished document, Nevada Department of Wildlife.

Ratliff, R.D. 1983. Nebraska sedge (*Carex nebraskensis* Dewey): Observations on shoot life history and management. J. Range Manage. 36:429-430.

Ratliff, R.D. and S.E. Westfall. 1987. Dry-year grazing and Nebraska sedge (*Carex nebraskensis*). Great basin Natur. 47:422-426.

Reece, P.E., J.T. Nichols, J.E. Brummer, R.K. Engel, and K.M. Eskridge. Harvest date and fertilizer effects on native and interseeded wetland meadows. J. Range Manage. 47:178-183.

Reed, P.R., Jr. 1988. National list of plant species that occur in wetlands: Southwest (Region 7). USFWS, Washington, D.C. Biol. Rep. 88(26.7). 71p.

Richardson, C.J. 1994. Ecological functions and human values in wetlands: a framework for assessing forestry impacts. Wetlands 14:1-9.

Roath, L.R. 1979. Cattle grazing habits and movements related to riparian habitat and forest ranges with inferences to acute dietary bovine pulmonary emphysema (ADBPE). PhD Thesis. Oreg. State Univ., Corvallis. 135pp.

Rodiek, J. 1980. The importance of Arizona's wetlands. Proc. Hydrol. Water Resour. of Ariz. and Southwest 10:249-252.

Rosgen, D.L. 1994. A classification of natural rivers. Catena 22:169-199.

Rumburg, C.B. and W.A. Sawyer. 1965. Response of wet-meadow vegetation to length and depth of surface water from wild-flood irrigation. Agron J. 57:245-247.

Skovlin, J.M. 1984. Impacts of grazing on wetlands and riparian habitat: a review of our knowledge. In National Research Council/National Academy of Sciences report on Developing Strategies for Rangeland Management. Westview Press, Boulder, CO. pp 1001-1104.

Smith, G.G. 1976. Effect of vegetation on lateral migration of anastomosed channels of a glacier meltwater river. Geol. Soc. of Amer. Bull. 87:857-860.

Tellman, B., H.J. Cortner, M.G. Wallace, L.F. DeBano and R.H. Hamre (tech. coords.). 1993. Riparian management: common threads and shared interests. USDA Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO. Gen. Tech. Rep. RM-226.

U.S. Environmental Protectional Agency. 1988. America's wetlands: our vital link between land and water. US Environ. Protect. Agency, Off. of Wetlands Protect. OPA-87-016. 9p.

Weigert, R.G. and F.C. Evans. 1964. Primary production and the disappearance of dead vegetation on an old field in southeastern Michigan. Ecology 45:49-63.

Wikberg, S., B.M. Svensson and B.A. Carlsson. 1994. Fitness, population growth rate and flowering in *Carex bigelowii*, a clonal sedge. Oikos 70:57-64.

Zube, E.H. and M.R. Sheehan. 1994. Desert riparian areas: Landscape perceptions and attitudes. Environ. Manage. 18:413-421.

Desired future condition: Fish habitat in southwestern riparian-stream habitats

John N. Rinne[1]

Abstract.—Riparian ecosystems in the southwestern United States provide valuable habitats for many living organisms including native fishes. An analysis of habitat components important to native fishes was made based on the literature, case histories, and unpublished and observational data. Results suggest a natural, surface water hydrograph and lack of introduced species of fishes being the two most critical habitat components delimiting sustainability of native fishes in the Southwest. Vegetation, channel characteristics and instream hydrological features (i.e. depth, velocity, and substrate) are important in distribution and sustainability of native fishes but secondary to the first two and are more important or relevant as management activities affect them. Desired Future Condition for native southwestern fishes ultimately depends on proper or desirable functioning of riparian ecosystems.

INTRODUCTION

Riparian ecosystems comprise a small portion (< 2%) of the total southwestern landscape. Their ecological and natural resource value in this region is vastly disproportionate to their relative surface area. These critical habitats are very important to a host of living organisms, and essential for many. Beginning in the 1970s (Ames 1977, Johnson and Jones 1977) these areas increasingly have become the object of greater interest to researchers and land managers (Johnson et al. 1985, Arizona Game and Fish 1995). In Region 3, the Southwestern Region of the U. S. Forest Service, these areas are afforded priority management status (USDA 1992a).

Within the category of obligate riparian-stream inhabitants are native fishes (Minckley 1973, Sublette et al. 1990, Rinne and Minckley 1991). Although the native fish fauna is not diverse in the Southwest (< ca 40 species), by default, surface water reaches of riparian areas provide critical habitats for native fishes. Most of the Southwest landscape is arid and comprised of the Sonoran Desert (Dunbier 1970). Desert landscapes are designated or delineated by their lack of water. Paradoxically, fishes require the medium of water to sustain themselves and are very intimately linked to riparian-stream areas.

The objectives of this paper are to

- Define habitat components in southwestern riparian-stream areas that are important to and influence or legislate fish habitat and populations,
- Present data and published literature that illustrate the state of knowledge and discuss the relevance of these habitat components to fish habitat, and
- Discuss the concept of "Desired Future Condition" as it relates to fish habitat in southwestern riparian-stream areas.

[1] *Fisheries Research Biologist, Rocky Mountain Forest and Range Experiment Station, Flagstaff, Arizona. Headquarters is located in Fort Collins, Colorado.*

KEY HABITAT COMPONENTS

Habitat components important to fishes are many, however, several physical and one biological factor are paramount. These are:

1. Water;
2. Riparian vegetation;
3. Nearstream features— streambanks, channel type and morphology;
4. Instream features —substrate composition and hydrological characteristics (e.g. width, depth, velocity, and gradient); and
5. Introduced species of fishes.

Water

Water is the controlling or driving component of all riparian ecosystems. The quantity and quality of this vital component in time and space is fundamental to fish habitat (Rinne 1991a, Heede and Rinne 1990) and distributions (Hubbs and Miller 1948). The vagaries of climate in the Southwest (Green and Sellers 1964) alone render extreme variability in quality and quantity of surface water in riparian areas. Variability is further accentuated by geological landscape features (Rinne in press a).

Annually, within a stream or given reach of stream in a brief (hours to days) time period, hydrology can range from presence of surface water, to intermittent pools, to lack of surface water, to raging torrents, and return to surface flow. Although native fishes appear to be uniquely adapted to these vicious cycles of habitat conditions (Minckley 1973, Deacon and Minckley 1974, Rinne and Minckley 1991, Rinne 1994, Stefferud and Rinne in press), none can sustain themselves once surface flow is totally lacking.

Because of arid climate, varying rainfall patterns, and topographic features (Rinne in press a), many channels and "arroyos" are ephemeral to intermittent throughout much of the year (Arizona Game and Fish Dept 1978). Most riparian areas containing naturally-flowing, perennial surface waters are associated with upper elevation (> 1,000 m) areas of the state. For example, rotometric measurement of surface area in the state of Arizona where most (> 95%) of the surface water is present suggests that about 10% of the landscape of the State contains most (95%) of the remaining naturally-flowing surface water. Most of these riparian stream systems lie along the Mogollon Rim in central Arizona.

Lower elevation (< 1000 m) mainstream rivers have been beheaded by numerous dams (Minckley 1973, Rinne 1991a, 1994, Rinne and Minckley 1991) and flow only intermittently or in a modified state (Arizona Game and Fish 1978). Other perennial streams in Arizona sustain base surface flow through effluents from municipal, industrial or agricultural effluents or spring sources. For example, the reach of the Salt River that passes through the greater Phoenix area once supported 15 species of native fishes (Minckley and Deacon 1968). Construction and closure of dams commencing with Roosevelt on the Salt River in 1911, followed by a series of subsequent, downstream dams on the Salt River, and two on the Verde completely dried this reach of river. Now only a host of introduced fishes persist in the intermittent surface water pools created by gravel mining operations and sewage effluents.

Natural hydrographs appear very important in sustaining native stream-dwelling fishes in the Southwest (Meffe and Minckley 1991, Rinne 1994, Rinne 1995b). Periodic flood events in southwestern rivers and streams appear to control or limit non-native fishes. Recent data from the Verde River suggest that both native and non-native fish populations are reduced by flooding, however, native populations quickly rebound (Stefferud and Rinne In Press) because of reproductive strategies adapted to post-flood events and stream channel habitat restructuring (Mueller 1984, Rinne 1995b). By contrast, reservoirs that alter and control the natural variability of southwestern river and stream hydrographs, favor the sustainability of introduced fishes.

Most of the above discussion relates to quantity of water and its relevance to fish habitat. Conceivably, quality of water should be an equally important component of fish habitat. There are few studies of water quality as they relate to fish habitat and native fish populations in the Southwest. Most species appear to survive in widely varying water quality conditions. Water temperatures in low desert riparian-stream systems may vary widely within a diel cycle and reach 30

degrees C or more (Deacon and Minckley 1974). Recent experiments indicate several native fishes sustain elevated heart rates under elevated water temperatures. Heart rates of 30-40 beats per minute in winter months at water temperatures of 15-20 C climb to twice that in the summer (unpublished data). Studies by Lee and Rinne (1980) indicate that the two native trouts in the Southwest do not succumb until water temperatures reach 29 degrees C. Other studies by Lowe et al. (1967) have examined dissolved oxygen requirements of several native species. Similarly, these species showed tolerance of a range of conditions.

The variability of water quality characteristics such as listed above is very great in time and space in the Southwest, often going from one extreme to another in a given reach of stream and often within a short (diel) time period. Therefore, research designed to determine the chronic effects of dissolved oxygen, turbidity and temperature may be of more academic than practical importance.

In summary, water is a precious commodity in the arid American Southwest. Water development has permitted ever-escalating ecomonic development of the region. The demand by humans for water alters flow regimes or completely removes from riparian-stream areas the most basic component of fish habitat—water. In a relative sense, the quantity of this habitat component and its natural variability in time and space are more important to native fishes than its quality.

Riparian vegetation

Woody vegetation within riparian-stream areas has been suggested as an important component of fish habitat. Woody streamside vegetation structure provides cover for fishes (Boussu 1954) and potentially shades stream habitats and reduces extremes of water temperature. Secondly, roots of woody vegetation stabilize streambanks and maintain their integrity in time and space. Thirdly, terrestrial insects occupying woody vegetation serve as a portion of the food source for fishes (Meehan et al. 1977). Finally, nearstream and streamside vegetation, once dead, produce "large woody debris (LWD)" to riparian stream systems.

Previously, herbaceous aquatic vegetation has not been considered an essential component of fish habitat. However, recent publications (Bridges et al. 1994.) and research being conducted by the Rocky Mountain Station, Flagstaff, Arizona, (Medina et al. in press) are implicating its importance to proper functioning of riparian-stream areas which, in turn, could be very important to fish habitat. However, the latter linkage or connection has not been substantiated.

LWD as a byproduct of riparian vegetation and as a component of fish habitat has been studied in great detail, albeit mostly in the Pacific Northwest (Meehan 1991, USDA 1992b). In the Northwest, the role of LWD as holding and rearing habitat for salmonids has been well-documented (Bryant 1983, Andrus et al 1988, Bisson et al 1982). The importance of LWD as fish habitat has also been demonstrated for both salmonids (Flebbe and Dolloff 1995) and selected warmwater species of fishes (Angermeier and Karr 1984) in the eastern United States. LWD has also been demonstrated to be important in structuring channel morphology (Keller 1979, Heede 1985, Cherry and Betscha 1989, Smith et al 1993, Richmond and Fausch in press). Only one of these studies (Heede 1985a) was conducted in the Southwest.

By comparison, the importance to fish habitat of live woody vegetation along riparian-stream corridors has not been unequivocally demonstrated in the Southwest. However, based on fish population estimates in two streams in the White Mountains, the contribution of Arizona alder (*Ulnus arizonae*) to Apache trout (*Oncorhynchus apache*) habitat and populations seems founded (Table 1). In two comparable streams lying alongside a contiguous ridge and less than two kilometers apart there appears to be a marked difference in trout density in reaches of stream having an alder component compared to those without streamside alder.

Table 1. Comparison of mean Apache trout density per kilometer of stream based on 40-m sample sections (n in parentheses) within vegetated and non-vegetated reaches of Boggy and Centerfire creeks, 1993-94.

	Vegetated		Un-vegetated	
Stream	1993	1994	1993	1994
Centerfire Creek	115 (22)	68 (14)	0 (16)	3.6 (7)
Boggy Creek	127 (13)	110 (16)	0 (9)	15 (13)

The function of LWD in providing habitat in form of cover or reduction of stream water temperatures or as a significant supplier of food likewise is undocumented. Rinne (1975) reported the probable importance of input of LWD into central Arizona reservoir ecosystems and Minckley and Rinne (1985) presented a historical review of LWD in the Southwest. Recently, Alexander and Rinne (in press) reported on the mobility of LWD in several streams impacted by a wildfire compared to one un-impacted stream. Rinne (1981) suggested that pools created by log stream improvement structures in several montane streams in southwestern New Mexico were of better quality and provided better fish habitat based on numbers, size, and biomass of Gila trout (*Oncorhynchus gilae*). However, 50% of these LWD structures artificially-imposed at right angles to flow were lost in flood events within a decade suggesting either design or more broad, watershed scale problems, or both.

The amounts of LWD in streams along a number of streams in the Mogollon Rim area of central Arizona and in the White Mountains of east-central Arizona is just beginning to be documented (Table 2). Compared to streams in the Pacific Northwest and northern Rocky Mountains (Richmond and Fausch In Press), montane streams in the Southwest have comparable amounts of LWD pieces per unit length of stream. Again, the role of LWD as fish habitat and the relationship to fish density and biomass in the Southwest is unstudied.

Table 2. Comparison of the variability of size classes of large woody debris in kilometer reaches of streams in the White Mountains of east-central Arizona and below the Mogollon Rim, central Arizona, 1995. Values are percentages of total. Size classes are: I = < 3 m X <0.15; II = > 3 m to 6 m X > 0.15 m to < 0.25 m; and III = > 6 m X > 0.25 m.

		Size Class		
	N	I	II	III
White Mountains				
Conklin	*298*	*55*	*32*	*13*
Bear	*303*	*62*	*25*	*13*
Double Cienega	*391*	*47*	*33*	*20*
Corduroy	*347*	*53*	*29*	*18*
Mamie	*529*	*56*	*29*	*15*
Coyote	*486*	*54*	*31*	*15*
Hanagan	*449*	*64*	*26*	*10*
Mogollon Rim				
Bray	*230*	*36*	*34*	*30*
Christopher	*185*	*30*	*42*	*28*
Webber	*439*	*41*	*40*	*19*
Horton	*162*	*43*	*48*	*9*
Tonto	*109*	*43*	*49*	*8*
Pine	*177*	*34*	*47*	*19*

Nearstream and instream features

Streambanks

Structure of streambanks and associated channel morphology may be important components of fish habitat. In first order upper elevation streams, undercut banks could serve as cover for native southwestern salmonids. Assessment of this physical feature can be made by bank angle measurements (Platts et al. 1987). Unstable streambanks can contribute extensive fine sediment to stream substrates and reduce establishment of both herbaceous and woody vegetation.

Stability of streambanks may be related to land management practices such as livestock grazing (Platts 1979, 1981, 1982, Rinne 1985) and timber harvest (Chamberlain et al. 1991). Both chiseling of streambanks by livestock hooves and logging roads crossing streams may induce "nick points" from which streambanks commence to unravel. Cooperative research between the Rocky Mountain Station, Apache Sitgreaves National Forest, and the Arizona Game and Fish Department on several streams in the White Mountains influenced by ungulate grazing is designed to define bank "damage" as influenced by ungulate grazing on first order streams.

Stream substrate

Substrate composition of a stream is a vital component of fish habitat. Fishes spawn on or the spawning products develop within stream substrates. Substrate composition is a product of parent geology, channel morphology, gradient, and watershed size and resultant stream hydrograph. The nature and amount of macroinvertebrates, the major food source for many native fishes, is dictated by stream substrate composition. The two native salmonids, Gila and Apache trout, spawn on gravel-pebble (8-32 mm) substrate (Harper 1978, Rinne 1982). The relative

amounts and distribution of these materials in streams in Arizona and New Mexico conceivably could limit trout populations. Further, the fine sediment (< 2 mm) component of substrate materials could also limit successful reproduction. Laboratory studies of the effects of fine sediment content of substrate on Apache trout fry emergence suggest that with increasing fine sediments, successful emergence decreases. Based on preliminary experimentation, at fine sediment concentrations of 20 %, Apache trout fry emergence is reduced by 24% relative to controls. At 30 % fines, reduction is 75%.

Pure populations of the Apache trout occur in streams in the White Mountains of Arizona on the Apache-Sitgreaves National Forest and the Fort Apache Indian Reservation. Recent (1980s) stream surveys of trout numbers and biomass indicate that streams sampled on the Reservation support a much higher (5-10 times) biomass of Apache trout than did a suite of Forest streams. A priori, this could be attributed, in part, to either 1) limitation of adequate-sized substrate materials for spawning or 2) excessive fine sediment content in stream substrates within Forest streams. On the basis of preliminary analyses of available spawning gravels in substrates and fine sediment content in Forest and Reservation streams, it appears that availability of optimum spawning gravels may be limiting within streams on the Forest (Tables 3, 4).

Rearrangement and scouring of substrate materials by flood events is apparently important to spawning of non-salmonid fishes in the Southwest. Mueller (1984) documented artificial disturbance of substrate materials by heavy equipment in a stream in southwestern New Mexico stimulated massive spawning by the speckled dace (*Rhinichthys osculus*). Apparently, such disturbance simulated a flood event. Kepner (1982) reported longfin dace (*Agosia chrysogaster*) displayed multiple spawning in Aravaipa Creek, an upper Sonoran Desert stream in southeastern Arizona, synchronized with flood events. Observations on the upper Verde River, Prescott National Forest, suggest multiple spawning of the desert sucker (*Catostomus clarki*) in the summer of 1995 following winter (February) flood events.

Table 3. Fine sediment (< 2 mm; % by weight) and spawning substrate for Apache trout (4-16 mm; % by weight) in substrates of three streams on the Fort Apache Indian Reservation, September 1994. Ranges of data are in parentheses.

Stream	N	Fines (< 2mm)	Spawning (2-16 mm)
Ord Cr.	20	25 (8-42)	37 (25-51)
Pacheta Cr.			
Upper	12	14 (4-21)	43 (26-49)
Lower	8	25 (11-44)	27 (21-36)
Reservation Cr.			
Upper	9	22 (16-27)	40 (26-53)
Lower	9	28 (19-32)	48 (42-61)
Mean of 58 Samples		22.7	31.4%

Table 4. Comparison of frequency of occurrence of mean percent fine sediment (< 2 mm) in substrates of 30 streams (n = 402) and percent by weight of spawning gravels for Apache trout (4-16 mm) in 1) 10 streams on the Apache Sitgreaves National Forest and 2) at five sites in three streams on the Fort Apache Indian Reservation (n = 58).

Management area	Percentage Concentration Class 0-10	11-20	21-30	31-40	41-50	51-60
Forest						
fines	10	14	6	0	0	0
spawning[1]	6	4	0	0	0	0
Reservation						
fines	0	1	4	0	0	0
spawning[2]	0	0	12	23	16	7

[1]*based on pebble counts*

[2]*based on sieve analyses of random substrate samples*

Channel morphology

Channel morphology has been categorized by Rosgen (1994). Based on channel typing and probable associated instream and nearstream features, one could hypothesize which channel types might serve as higher quality fish habitat. However, no information are available on the relative quality of fish habitat afforded by differing channel types. This is an area that needs research. Medina and Martin (1985) reported dramatic changes in channel morphology of Mcknight Creek resulting from a wildfire on its watershed 50 years previous. Populations of Gila trout appear to be affected by the combination of flood events and channel degradation (Rinne in press c).

Hydrologic features

Width, depth and velocity of water in riparian-stream systems are important to fish habitat. Because water is the medium in which fish spend all their life, respective species select different combinations of these aquatic habitat characteristics to reproduce, feed, and rest or hide in (Heede and Rinne 1990, Rinne 1988, 1989, 1991a, 1994). The Gila trout for example has been labeled a pool dweller in headwater streams in southwestern New Mexico (Rinne 1978). Although the seven native species of fishes in Aravaipa Creek overlap and utilize similar physical habitats, they partition niches based on food supply (Rinne 1992, 1995b). Recent study of a native fish community on the upper Verde River indicates consistent capture of respective species in the same habitat velocities (i.e. high and low gradient riffles, glides, runs, and pools; unpublished data) over a 60-km reach of river.

Velocity of water is controlled largely by stream gradient. Substrate composition, in turn, is a result of velocity of water. The interactions of these habitat features work in combination to legislate fish habitat, distributions and populations. Some native fish species appear to be limited in distribution by stream gradient. The Little Colorado spinedace appears to move downstream readily when placed in higher gradient (> 3%) streams (Rinne In press b). Similarly, the Rio Grande sucker (*Catostomus plebeius*) is not distributed in reaches of streams in northern New Mexico that have gradients greater than 3% (Bob Calamusso, pers comm.).

Introduced fishes

A primary biological influence on aquatic habitats and their suitability for native fishes is the presence or absence of introduced, non-native fishes. Numerous case history studies, observational data and the published literature (Meffe 1985, Minckley and Deacon 1991, Blinn et al. 1993, Douglas et al. 1994, Rinne 1990, 1994) combined with more recent laboratory studies (Rinne and Alexander in press) indicate that the presence of non-native fishes is perhaps a dominant factor over physical habitat in delimiting native fish distributions. Through the mechanisms of predation, hybridization, and competition acting singularly or in combination , non-native fish species effectively replace native species (Rinne 1994). As indicated above, replacement is further facilitated by damming of riparian-stream areas and altering natural hydrographs, reducing variability in flows and stability of aquatic habitats.

DESIRED FUTURE CONDITION AND FISH HABITAT IN RIPARIAN HABITATS

As an alternative , one could change the terminology for the "F" of the acronym DFC or "desired future condition" to effect the concept of "desired fisheries condition." A modification of the concept is in agreement with "Desirable Functioning Processes" proposed by Medina et al. (this issue) and "proper functioning condition" by Bridges et al. (1994). Considering both, riparian-streams systems must be properly functioning hydrologically, biologically and physically in order to provide optimum fish habitat for native fishes. Accordingly, I will rank or prioritize the above-discussed habitat features into a working, functioning context that will sustain native fishes in southwestern riparian-stream ecosystems.

Of first priority, is surface water quantity. In absence of this fish habitat component, the other factors are rendered irrelevant. Because of the obligatory relationship of fish to surface water this habitat factor is of number one priority. Any management activities that contribute to or in themselves effect reducing flow to subsurface levels for even a brief period of time must be avoided. Unfavorable water quality may come as a result of reduced flow, but many native species often will survive these harsh, unfavorable conditions until the next spate replenishes surface flow. Nevertheless, water quantity is of greater importance than is water quality as a limiting fish habitat factor. Instream flow designation and purchase of water rights are two viable strategies to insured surface water for fish habitat. However, instream flow consisting of a natural hydrograph is preferrable over sustained "minimum flows."

Introduced fishes are the next most important limiting factor to viable native fish habitat. If absent from reaches of streams or entire watersheds or stream systems, all effort should be made

to prevent entry of non-native fish species. If present, land managers should be vigilant of opportunities to remove them from these systems. Removal of non-native salmonids has been done very successfully with Apache and Gila trout management in montane streams in the Southwest (Rinne et al. 1981, Rinne and Turner 1991). Removal of non-native fishes becomes more difficult as one moves downstream into larger riparian-stream ecosystems and into reaches of greater habitat complexity and variable watershed ownership and uses. In these larger riparian-stream systems such as the upper Verde, Salt and Gila rivers, a natural hydrograph is the primary factor that will effect maintenance of native fish habitat by periodic reduction of non-native fish populations.

Another management alternative is to designate watersheds for native fish management and others for introduced, primarily sport fish management (Rinne and Janisch 1995). The designation of the upper West Fork of the Black River on the Apache Sitgreaves National Forest is a primary example of this management strategy. Artificial fish barriers (Rinne and Turner 1991) are often required to effect such conservation efforts, unless natural barriers are present. Sustaining the absence of non-natives or removal of these species if present, superimposed upon maintenance of surface waters is probably 80-90% of the battle in providing suitable habitat for southwestern native fishes inhabiting riparian-stream ecosystems.

The remaining contribution to establishing, maintaining, or enhancing other fish habitat factors discussed above will come through proper land management (Rinne 1990). All management must be done in the context of the watershed as being a major effector of riparian habitat structure and function (Platts and Rinne 1985, Debano and Schmidt 1989, Rinne 1990, Reid 1994). The linkages between the watershed and the riparian area, between riparian form and structure and fish habitat must be addressed in future research (Likens and Borman 1974). Ultimately, the linkage between fish habitat and fish populations must be defined and modeled. However, based on the efforts of Fausch et al. (1988) modeling may be very difficult and if accomplishable, will only be achievable at a local or regional scale. Clarkson and Wilson (1995) evaluated a suite of habitat variables measured through the General Aquatic Wildlife methodology and Habitat Condition Indices for three dozen streams in the White Mountains of Arizona. Results suggest that relating and predicting fish populations and biomass by habitat factors, if accomplishable at all, will be only on a local or regional basis scale.

ACKNOWLEDGMENTS

The White Mountain Apache Tribe is gratefully acknowledged for granting permission to collect sediment samples on Reservation streams. Kelly Meyer of the Tribal Fish and Wildlife Department is specifically acknowledged for field assistance.

LITERATURE CITED

Alexander, M. M. and J. N. Rinne. in press. The effects of wildfire on southwestern riparian-aquatic ecosystems: Large woody organic debris. *In*, Hydrology and Water Resources in Arizona and the Southwest 17. Arizona Sect., Amer. Water Resour. Assoc., Hydrol. Sect. AZ-NV Acad of Sciences, and The Ariz. Hydrol. Soc. Northern Arizona University, Flagstaff Arizona.

Ames, C. R. 1977. Wildlife conflicts in riparian management: Grazing. *In*, R. R. Johnson, and D. A. Jones (tech. coord.), Importance, Preservation, and Management of Riparian Habitat. USDA For. Serv. Gen. Tech. Rep. RM-43:39-51. Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.

Andrus, C.W., B.A. Long, and H.A. Froehlich. 1988. Woody Debris and Its Contribution to Pool Formation in a Coastal Stream 50 Years after Logging. Canadian Journal of Fish and Aquatic Science 45:2080-2086.

Angermeier, P.L. and J.R. Karr. 1984. Relationships Between Woody Debris and Fish Habitat in a Small Warmwater Stream. Transactions of the American Fisheries Society 113:716-726.

Arizona Game and Fish Department. 1978. Drainage Map of Arizona showing Perennial Streams and some Important Wetlands. Ariz. Game and Fish Dept., Phoenix, Ariz.

Arizona Game and Fish Department. 1995. Proceedings of the Tonto National Forest Aquatic

and Riparian Ecosystem Workshop. Mesa, Arizona, April, 1995.

Bisson, P.A., J.A. Nielsen, R.A. Palmason, and L.E. Grove. 1982. "A system of Naming Habitat Types in Small Streams with examples of Habitat Utilization by Salmonids During Low Streamflow", in Armantrout, N.A. (Ed.). Acquisition and Utilization of Aquatic Habitat Inventory Information, American Fisheries Society, Western Division, Symposium Proceedings, Portland, Oregon, 62-73.

Blinn, D. W., C. Runck, D. A. Clark, and J. N. Rinne. 1993. Effects of rainbow trout predation on Little Colorado spinedace. Trans. Amer. Fish. Soc. 122: 130-143.

Boussu, M. F. 1954. Relationship between trout populations and cover of a small stream. J. Wildl. Mange. 18(2): 229-239.

Bridges, C., W. Hagenbuck, R. Krapf, S. Leonard, and D. Prichard. 1994. Riparian area management: Process for assessing proper functioning condition for lentic riparian-wetland areas. USDI Bur. of Land Management Tech. Rept. WRP-1737-11., Denver, Colo.

Bryant, M. 1983. The Role and Management of Woody Debris in West Coast Salmonid Nursery Streams. North American Journal of Fisheries Management 3:322-330.

Chamberlain, T. W., R. D. Harr, and F. H. Everest. 1991. Timber harvesting, silviculture, and watershed processes, pp- 181-206. *In*, W. R. Meehan (ed.) Influences of Forest and Rangeland Management on Salmonid Fishes and their Habitats.

Cherry, J. and R.L. Beschta. 1989. Coarse Woody Debris and Channel Morphology: A Flume Study. Water Resources Bulletin 25(5):1031-1036.

Clarkson, R. W., and J. R. Wilson. 1995. Trout biomass and stream habitat relationships in the White Mountains area, east-central Arizona. Trans. Amer. Fish. Soc. 124(4): 599-612.

Deacon, J. E. and W. L. Minckley. 1974. Desert fishes, pp 385-488. *In*, G. W. Brown Jr. (ed.) Desert Biology. Vol 2. Academic Press.

DeBano, L.F. and L.J. Schmidt. 1989. Improving southwestern riparian areas through watershed management. United States Department of Agriculture, Forest Service, General Technical Report RM-182. p. 1-33.

Douglas, M. E., P. C. Marsh, and W. L. Minckley. 1994. Indigenous fishes of western North America and the hypothesis of competitive displacement: *Meda fulgida* (Cyprinidae) as a case study. Copeia 1994(1): 9-19.

Dunbier, R. 1970. The Sonoran Desert. Its geography, economy, and people. Univ. Ariz. Press. Tucson, Arizona. 426 pp.

Flebbe, P. A. and C. A. Dolloff. 1995. Trout use of woody debris and habitat in Appalachian Wilderness streams of North Carolina. N. Amer. J. Fish. Manage. 15(3): 579-590.

Green, C.R., and W.D. Sellers (editors). 1964. Arizona climate. University of Arizona Press, Tucson. p. 503.

Harper, K. C. 1978. Biology of a southwestern salmonid, *Salmo apache* (Miller 1972), pp. 99-111. In, J. R. Moring (ed.) Proc. Wild Trout-Catchable Trout Sympos., Eugene, Oregon, February 15-17, 1978.

Heede, B. H. 1985. Interactions between streamside vegetation and stream dynamics. USDA Forest Service, General Technical Report RM 120: 54-58.

Heede, B. H. and J. N. Rinne. 1990. Hydrodynamics and fluvial morphologic processes: Implications for fisheries management and research. N. Amer. J. Fisheries Manage 10: 249-268.

Hubbs, C.L., and R.R. Miller. 1948. Correlation between fish distribution and hydrographic history in the desert basins of western United States. Bulletin University of Utah 38(20):18-166.

Johnson, R. R. and D. A. Jones, (tech. coords.). 1977. Importance, preservation and management of riparian habitat: A symposium. USDA For. Serv. Gen. Tech. Rep. RM-43: 1-217. Rocky Mtn. For. and Range. Exp. Sta., Fort Collins, Colo.

Kepner, W. 1982. Reproduction biology of longfin dace, *Agosia chrysogaster*, in a Sonoran Desert Stream. Unpubl. M.S. Thesis, Arizona State Univ.

Keller, E.A. and J. Swanson. 1979. Effects of large organic material on channel form and fluvial processes. Earth Surface Processes 4: 361-380.

Lee, R. M. and J. N. Rinne. 1980. Critical thermal maxima of five trout species in the southwestern United States. Trans. Am. Fish. Soc. 109: 632-635.

Likens, G. E. and F. H. Bormann. 1974. Linkages between terrestrial and aquatic ecosystems. Bioscience 24(8): 447-456.

Medina, A.L. and C. Martin. 1988. Stream channel and vegetation changes in sections of Mcknight Creek, New Mexico. Great Basin Naturalist 48(3):373-381.

Medina, A. L., M. B. Baker, and D. G. Neary. 1996. Desirable functional processes: A conceptual approach for evaluating ecological condition *In* USDA Forest and Range Experiment Station, General Technical Report, Fort Collins, CO, this issue.

Meehan, W. R. (Ed.). 1991. Influences of forest and rangeland management on salmonid fishes and their habitats. Amer. Fish. Soc. Spec. Publ. 19:1-751.

Meehan, W. R., F. J. Swanson, and J. R. Sedell. 1977. Influences of riparian vegetation on aquatic ecosystems with particular reference to salmonid fishes and their food supply, pp. 137-145. *In*, R. R. Johnson and D. A. Jones (tech. coordinators) Importance, preservation and management of riparian habitat: a symposium. USDA Gen. Tech. Rep. RM-43, Fort Collins, Colorado.

Meffe, G. K. 1985. Predation and species replacement in American southwestern fishes: a case study. Southwest. Naturalist 30: 173-187.

Meffe, G. K. and W. L. Minckley. 1987. Persistence and stability of fish and invertebrate assemblages in a repeatedly disturbed Sonoran Desert stream. Amer. Midl. Nat. 117(1): 177-191.

Minckley W.L. and J.E. Deacon. 1968. Southwestern fishes and the enigma of "endangered species". Science. 159: 1424-1432.

Minckley, W.L. and J.N. Rinne. 1985. Large Woody Debris in Hot-Desert Streams: An Historical Review. Desert Plants 7(3): 142 153.

Minckley, W. L. and J. E. Deacon. 1991. Battle against extinction: Native fish management in the American West. Univ. Ariz. Press, Tucson. 517 pp.

Mueller, G. 1984. Spawning by *Rhinichthys osculus* (Cyprinidae) in the San Francisco River, New Mexico. The Southwestern Naturalist 29:354-356.

Platts, W. S. 1979. Livestock grazing and riparian-stream ecosystems: An overview, p. 39-45. *In*, O. B. Cope (ed.), Grazing and riparian-stream ecosystems: A forum. Trout Unlimited, Inc.

Platts, W. S. 1981. Effects of sheep grazing on a riparian-stream environment. USDA For. Serv. Res. Note INT-307: 1-6. Intmtn.. For. and Range Exp. Stn., Ogden, Utah.

Platts, W. S. 1982. Livestock and riparian fishery interactions: what are the facts? Trans. N. A. Wildl. and Nat. Res. Conf. 47: 507-515.

Platts et al. 1987. Methods for Evaluating Riparian Habitats With Applications to Management. General Technical Report INT-221:83-93.

Platts, W.S. and J.N. Rinne. 1985. Riparian and stream enhancement management research in the Rocky Mountains. North American Journal of Fisheries Management 5:115-125.

Reid, L. M. Research and cumulative watershed effects. USDA Forest Service Gen. Tech. Rept. PSW-141: 1-118.

Rinne, J. N. 1975. Hydrology of the Salt River and its reservoirs, central Arizona. Jour. Ariz. Acad. Sci. 10(2):75-86.

Rinne, J. N. 1978. Development of methods of population estimation and habitat evaluation for management of the Arizona and Gila trouts. *In*. John R. Moring, (ed.), Proc. Wild Trout - Catchable Trout Symposium, Eugene, Ore., Feb. 15-17, 1978.

Rinne, J. N. 1981. Stream habitat improvement and native southwestern trouts. USDA, For. Serv. Res. Note RM-409: 1-4.

Rinne, J.N. 1982. Movement, home range, and growth of a rare southwestern trout in improved and unimproved habitats. North American Journal of Fisheries Management 2:150-157.

Rinne, J. N. 1985. Livestock grazing effects on southwestern streams: A complex research problem, pp. 295-299. *In* Johnson, R. R. et al. (tech eds). Proc. First North American Riparian Conference. Riparian ecosystems and their management: reconciling and conflicting uses. USDA For. Serv. Gen. Tech. Rep. RM-120:1-523.

Rinne, J. N. 1989. Minimizing grazing effects on riparian stream habitats: Recommendations for research and management, pp 15-28. *In*, G. Flock (ed), Proc. National Sympos. for Enhancing States/Wetland Management Programs. North American Lake Management Society, Chicago, Ill. May 1989.

Rinne, J. N. 1989b. Physical habitat use by loach minnow, *Tiaroga cobitis* (Pices: Cyprinidae), in southwestern (USA) desert streams. Southwestern Nat. 34(1):109-117.

Rinne, J.N. 1990. The utility of stream habitat and biota for identifying potential conflicting forest land uses: montane riparian areas. Forest Ecology and Management 33/34:363-383.

Rinne, J. N. 1991a. An approach to management and conservation of a declining regional native

fish fauna: Southwestern United States, pp. 56-60 *In* N. Maruyama et al. (eds)-wildlife conservative: Present trends and perspectives for the 21st Century. Proc. Internatl. Symp. Wildl. Conserv., 5th Internatl. Congr. Zool., Tsukuba and Yokohama, Japan.

Rinne, J. N. 1991b. Habitat use by spikedace, *Meda fulgida* (Pisces: Cyprinidae) in southwestern streams with reference to probable habitat competition by red shiner, *Notropis lutrensis* (Pisces: Cyprinidae). The Southwestern Nat. 36(1): 7-13.

Rinne, J. N. 1992. Physical habitat utilization of fish in a Sonoran Desert stream, Arizona, southwestern United States. Ecol. Freshwater Fishes 1: 1-8.

Rinne, J. N. 1994. Declining southwestern aquatic habitats and fishes: Are they sustainable? Sustainability Symposium. USDA For. Service, Gen. Tech. Rep. RM-247: 256-265.

Rinne, J. N. 1995a. The effects of introduced fishes on native fishes: Arizona, southwestern United States. World Fisheries Conference. April 15-19, 1991, Athens, Greece. Vol 3: 145-158.

Rinne, J. N. 1995b. Stream fishes, pp 1-21. *In*, Tonto National Forest Aquatic and Riparian Ecosystem Workshop. April 18-22, 1995. Arizona Game and Fish Department, Phoenix, Arizona.

Rinne, J. N. In Press a. Sky island aquatic resources: habitats and refugia for native fishes. USDA For. Serv. Gen Tech. Rep. RM-.

Rinne, J. N. In Press b. Native fish replacement in the Southwest: The interactions of hydrology and predation. *In*, Hydrology and Water Resources in Arizona and the Southwest. 17. Ariz. Sect. Amer. Water Resour. Assoc., Hydrol Sect. AZ-NV Acad of Sciences, and The Ariz. Hydrol. Soc. Northern Arizona University, Flagstaff Arizona.

Rinne, J. N. in press c. Southwestern wildfires: Effects on fishes and aquatic macroinvertebrates and management implications. N. Amer. J. Fish. Manage.

Rinne, J. N. and W. L. Minckley. 1985. Patterns of variation and distribution in Apache trout (*Salmo apache*) relative to co-occurrence with introduced salmonids. Copeia 1985: 285-292.

Rinne, J. N. and W. L. Minckley. 1991. Inland native fishes of the Southwest; a declining natural resource. USDA For. Serv. Gen. Tech. Rep. RM-206: 1-45. Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado.

Rinne, J. N. and P. R. Turner. 1991. Reclamation and alteration as management techniques, and a review of methodology in stream renovation, pp 219-246. *In*, W.L. Minckley and J. E. Deacon. (eds.), Battle Against Extinction: Native fish management in the American West. Univ. Ariz. Press, Tucson.

Rinne, J. N. and J. Janisch. 1995. Coldwater fish stocking and native fishes in Arizona: Past, present and future, pp 397-406. *In*, J. L. Schramm and R. G. Piper (eds), Use and effects of cultured fishes in aquatic ecosystems. Amer. Fish. Soc. Symposium 15. Bethesda Maryland.

Rinne, J. N. and M. Alexander. in press. Non-native salmonid predation on two threatened native species: Preliminary observations of field and laboratory studies. Proc. Desert Fishes Council 26.

Rinne, J. N., W. L. Minckley, and J. N. Hanson. 1981. Chemical Treatment of Ord Creek, Apache County, Arizona, to re-establish Arizona trout. Arizona-New Mexico Acad. Sci. 16: 74-78.

Rosgen, D. L. 1994. A classification of natural rivers Catena. 22(3): 169-199.

Stefferud J. A. and J. N. Rinne. In Press. Sustainability of fishes in a desert river: The roles of streamflow and introduced fishes. *In*, Hydrology and Water Resources in Arizona and the Southwest 17. AZ Section. Amer. Water Resour. Assoc., Hydrol Sect. AZ-NV Acad of Sciences, and The Ariz. Hydrol. Soc. Northern Arizona University, Flagstaff Arizona.

Sublette, J. E., M. D. Hatch, and M. Sublette. 1990. The fishes of New Mexico. Univ. of New Mexico Press, Albuquerque.

U. S. D. A. 1992a. Ecology-based resource management. Albuquerque, New Mexico

U. S. D. A. 1992b. Woody debris Packet # 1, literature included papers. Nat. Aquatic. Monitoring Center, Utah State Univ.

Management plan for the Rio Cebolla watershed Sandoval County and Rio Arriba County, New Mexico

Noreen A. Breeding[1]

Abstract.—*The upper 16.8 miles of the Rio Cebolla watershed were studied to identify water-related management concerns. Land ownership is divided among private individuals, the New Mexico Game and Fish Department, and the U.S. Forest Service. Recreation is the predominant activity, particularly fishing and camping. Other major land users are residents of the Seven Springs Community, cattle grazers, and fish hatchery employees. In 1994-95 a program to reintroduce now vanished Rio Grande cutthroat trout into the less accessible reaches of the river was undertaken.*

Water quality problems include eutrophication of Fenton Lake reservoir, riparian damage, and heavy sediment in the river. As a result, fish productivity is low, fishing is poor, and scenic enjoyment is spoiled. A watershed management plan is proposed to remedy these problems. Implementation of the plan is cost-effective, as the benefit/cost ratio equals 2.5. Benefits are derived from the value of an angler day.

INTRODUCTION

Delineating the extent of a watershed or drainage basin may be the most appropriate means of defining the area to be managed in protecting water resources. In developing a plan to improve and protect trout habitat in the Rio Cebolla, activities in the entire watershed are considered and the watershed as a whole is taken as the management unit.

PHYSICAL DESCRIPTION OF THE WATERSHED

The Rio Cebolla is a small perennial stream in the Jemez Mountains of northern New Mexico. It lies in the western section of the Santa Fe National Forest about 70 miles north of Albuquerque. The uppermost 16.8 miles of the river were selected for this project. This segment extends from the source at 9820′ in elevation to the dam at Fenton Lake Reservoir at 7674′. At 2.4% the gradient of the river is gentle. For the amount of activity it supports the river is remarkably small. In 1994 and 1995 stream flow ranged from a low of 3 cfs (cubic feet/second) to a high of 46 cfs. Stream width varied from less than two feet to eight feet; depth from six inches to 18 inches.

The downstream half of the river is situated in a steep, narrow canyon that is 800′ deep in places. Meadows occupy about five miles of the confined riparian area there. The slopes and the rest of the valley is densely wooded with evergreen forest. The ridge along the eastern edge of the watershed is the rim of the ancient Valles caldera. For this reason, the rock of the area is primarily volcanic—tuff, rhyolite, andesite, and pumice, and the soil is very porous and highly erodible.

The watershed covers about 47 square miles. Land ownership is shared by three entities, the U.S. government, the N.M. Game and Fish Department, and the members of the Seven Springs Community. By far the largest portion of the land is controlled by the Forest Service. However, the other two entities own important sections of the riparian corridor.

[1] *University of New Mexico, Geography Department, Albuquerque, New Mexico.*

CURRENT AND PAST LAND USES

In 1798 the area now in the Santa Fe National Forest south of Fenton Lake was deeded to the Canon de San Diego Grant. Sheep grazing was recorded there in the 1870s. From 1920 to 1973 the New Mexico Lumber & Timber Company logged the area extensively. In 1892 Elijah M. Fenton established a homestead and ranch along the river just north of the Grant territory. He began subdividing his land and selling lots in what is now the Seven Springs Community in 1913. In 1930s the N.M. Game and Fish Department purchased land from Fenton for a fish hatchery and reservoir. Fenton Lake reservoir was built in 1946 and the state park surrounding it was created in 1984 to regulate use of the area.

In terms of numbers of participants, recreation is the predominant land use today. Camping and fishing are very popular. There are three campgrounds in the watershed; a developed one at Fenton Lake State Park and two primitive campgrounds, one owned by the Dept. of Game and Fish and the other by the Forest Service. A state fish hatchery is also situated along the river. In 1994 the Forest Service requested that the Game and Fish Dept. reintroduce the Rio Grande cutthroat trout to the Rio Cebolla. It had been the native fish there until it vanished after the introduction of the exotic brown trout. The Game and Fish Dept. are removing all non-native fish from one section of the river into which they will transplant 500-1000 native cutthroats taken from local streams. This project is scheduled to be completed during the summer of 1995.

Another group who have a major impact on the watershed is the Seven Springs Community. It consists of about 50-150 year round residents dispersed among several dozen dwellings located along about two miles of the river. Many of the buildings are closely spaced along the river banks and several occupy wetlands. Cattle grazing is ubiquitous, with the possible exception of the fish hatchery grounds. In the summer of 1994 the National Forest pasture upstream of the Seven Springs Campground was severely overgrazed. Roads also have a major impact because they are numerous, unpaved, and heavily used. State Highway 126 is the major route. It closely parallels the river for about 7 miles, crossing it several times on small bridges. Forest roads in the canyon bottom were closed to the public north of Seven Springs Campground in 1994 to protect fish and wildlife habitat. Heavy logging took place in the early 20th century, but there is little going on now. The last cut occurred at the head of Barley Canyon in the early 1990s.

METHODOLOGIES USED TO LOCATE SITES OF EROSION AND SOURCES OF WATER POLLUTION

GIS (Geographic Information Systems technologies) were used to delineate the watershed boundary from which watershed area and river length were calculated. Slopes were also categorized by steepness. By overlaying roads and other land uses with slopes and water courses potential sites for erosion and water pollution were pinpointed. Only one road crosses a slope steeper than 60%. By creating buffer zones of varying widths along the river, it was shown that many roads and residences occupy the riparian corridor.

Water samples were collected at five sites along the river ten times in twelve months. They were chemically tested for concentrations of nitrate nitrogen and phosphorus. Results show that nitrate nitrogen levels are not particularly elevated. How-ever, phosphorus levels frequently exceeded the New Mexico standard for a high quality cold water fishery of 0.1 mg/l. As readings at none of the sites was consistently higher than readings at the other sites, pollution sources appear to be non-point. Nitrate is not a major source of nitrogen in the Rio Cebolla. Further testing might find ammonia to be a significant nitrogen source.

The author has walked the length of the river and many side canyons in the study area and visited the watershed in all seasons of the year. The results of heavy use by humans and cattle are widely evident. Riparian vegetation and streams banks are damaged in many areas. Roads are very dusty. The soil is fragile and high erodible. The reservoir is thick with algae during the summer.

WATER QUALITY PROBLEMS

Fenton Lake reservoir regularly suffers from eutrophication. Algae blooms occurred in 1982 and 1988. The water is shallow and consequently warm

in the summer. Levels of dissolved oxygen at this time of year are low and pH is often greater than ten. Macrophyte growth along the shoreline is dense. Shallowness is due to the natural morphology of the reservoir site, rather than to excessive sedimentation. Sedimentation rates appear to be low.

Sediment smothers the stream bed of the Rio Cebolla in many stretches. There is also a lot of riparian damage. Banks are denuded and broken down due to camping, roads, building construction, and overgrazing.

Fish are, at present, the beings most adversely affected by the water pollution. Their productivity in the watershed is relatively low. The lake cannot be stocked in the summer because pH shock kills fish added to the water. The riparian damage and excessive algae and dense macrophytes in the reservoir create unpleasant experiences for people.

WATERSHED MANAGEMENT PLAN

Because of heavy watershed use and obvious degradation of fish productivity, water quality, and riparian areas, there is need for a management plan that will provide protection for the watershed from further abuse. This is especially true as no watershed wide plan exists now. The goals of the plan would be to ensure the success of the Rio Grande cutthroat trout reintroduction program while protecting riparian areas to permit them to recover, and improving water quality. Preservation of the 'natural' qualities of the area for future users is another goal.

The suggested implementation strategy for the plan would be to form a volunteer coalition of watershed users, landowners, and Forest Service and Game and Fish Department representatives. The coalition would have the responsibility for developing a watershed management plan, implementing improvements, acquiring funding, and employing a part-time administrator to keep the plan on schedule.

Recommended components of a watershed management plan for the Rio Cebolla are listed below. This plan would be in effect for 20 years.

- Complete the Rio Grande cutthroat trout reintroduction and, after 5 years, extend the range of these fish downstream.
- Close roads in riparian areas.
- Exclude cattle from riparian areas.
- Convert Seven Springs Campground to a pedestrian day use area north of the fish hatchery.
- Create a 10 meter wide buffer zone along the river for use of anglers and pedestrians only.
- Delineate a 60 meter wide buffer zone along the river inside of which roads and new construction would be prohibited.
- Gather water quality data continuously to monitor changing conditions.

BENEFIT/COST ANALYSIS OF MANAGEMENT PLAN

Benefit/Cost analysis can help determine the effectiveness of management plans. In this case, benefits are derived from income from anglers. The value of an angler day is $57.60 as determined by the Travel Cost Method (TCM).

Travel Cost = (Distance X Cost of Operating Vehicle) + (Travel Time X Cost of Time)

$57.60 = (140 miles X $0.29/mile) + (4 hours X $4.25/hour)

The distance from Albuquerque to Fenton Lake round trip is 140 miles. About 4 hours are required to drive this distance. Minimum wage was used as the value of travel time.

It is estimated that there will be about 10,000 angler days on the Rio Cebolla in 1995. After 5 years, with the management plan in place, trout productivity should increase by 200%. The number of angler days should increase at the same rate. Over 20 years, the value of angler days with the plan would exceed the value of angler days without the plan by $2,541,000 using an 8% discount factor, as shown in Tables 1 and 2.

The costs of the watershed management plan belong to 7 main categories. During the first year, the cutthroat trout reintroduction program must be paid for. After the fish become established in 5 years, this expense will recur as native trout territory is expanded downstream. The Forest Service will lose income from grazing when cattle are excluded from riparian areas. This will amount to $1.98 per AUM for 168 cattle for 2 weeks per year. The price of fence materials for a 3.5 mile long, 10 meter wide buffer zone along the river is another

Table 1.—Value of fishing with watershed management plan (8% discount).

Year	Number of angler days	Value of an angler day	Annual value of (000)	Present value of (000)
1995	10,000	$57.60	$576	$576
1996	10,000	$57.60	$576	$533
1997	10,000	$57.60	$576	$494
1998	10,000	$57.60	$576	$457
1999	10,000	$57.60	$576	$423
2000	10,760	$57.60	$620	$422
2001	11,578	$57.60	$667	$420
2002	12,457	$57.60	$718	$419
2003	13,404	$57.60	$772	$417
2004	14,422	$57.60	$831	$416
2005	15,518	$57.60	$894	$414
2006	16,698	$57.60	$962	$412
2007	17,967	$57.60	$1,035	$411
2008	19,332	$57.60	$1,114	$409
2009	20,801	$57.60	$1,198	$408
2010	22,381	$57.60	$1,289	$406
2011	24,082	$57.60	$1,387	$405
2012	25,912	$57.60	$1,493	$403
2013	27,881	$57.60	$1,606	$402
2014	30,000	$57.60	$1,728	$400
Total	333,194		$19,192	$8,649

Notes:

Discount rate for present value = 0.08

Annual discount factor = 1.08

Increase in angler days = 200%

Table 2.—Value of fishing without watershed management plan (8% discount).

Year	Number of angler days	Value of an angler day	Annual value of (000)	Present value of (000)
1995	10,000	$57.60	$576	$576
1996	10,000	$57.60	$576	$533
1997	10,000	$57.60	$576	$494
1998	10,000	$57.60	$576	$457
1999	10,000	$57.60	$576	$423
2000	10,000	$57.60	$576	$392
2001	10,000	$57.60	$576	$363
2002	10,000	$57.60	$576	$336
2003	10,000	$57.60	$576	$311
2004	10,000	$57.60	$576	$288
2005	10,000	$57.60	$576	$267
2006	10,000	$57.60	$576	$247
2007	10,000	$57.60	$576	$229
2008	10,000	$57.60	$576	$212
2009	10,000	$57.60	$576	$196
2010	10,000	$57.60	$576	$182
2011	10,000	$57.60	$576	$168
2012	10,000	$57.60	$576	$156
2013	10,000	$57.60	$576	$144
2014	10,000	$57.60	$576	$133
Total	200,000		$11,520	$6,108

Notes:

Discount rate for present value = 0.08

Annual discount factor = 1.08

Increase in angler days = 200%

Table 3: Benefit/cost analysis of watershed management plan

8% Discount	4% Discount		
Benefits:			
Angler Income		$2,541,000	4,327,000
Costs:			
Cutthroat Trout Program		$30,000	30,000
Lost Grazing Income		1,764	2,351
Administration		265,090	353,349
Fence materials for 10 meter buffer		14,434	14,434
Water Quality Monitoring		26,509	35,335
Cutthroat Trout Expansion		19,662	24,184
Parking Lot		370,370	384,615
	Total	$727,829	844,268
Net Benefits *(Benefits - Costs) =*		1,813,171	3,382,732

Benefits / Costs: *1,813,171 / 727,829 = 2.5 at 8% discount or*

3,482,732 / 844,268 = 4.1 at 4% discount

cost. Volunteer labor will be used to erect the fence. The salary of a part-time administrator over 20 years and the purchase of water quality monitoring supplies and laboratory fees are additional costs. The largest single expense will be for closing the Seven Springs Campground, removing unwanted structures, and constructing a trail head parking lot for day users just north of the fish hatchery. Table 3 displays the benefit /cost analysis of the watershed management program. The final benefit/cost ratio of 2.5/1 indicates that benefits will exceed costs in monetary terms by a factor of 2.5 times (at an 8% discount).

CONCLUSIONS

With study of the Rio Cebolla watershed and development of a management plan, several conclusions have become apparent. Upstream of Fenton Lake dam the watershed is subject to heavy use from campers, anglers, a fish hatchery, cattle, and residents. As a result, water quality and riparian health are definitely degraded. However, measures to halt and reverse degradation, such as outlined in the management plan, would be cost effective as well as providing multiple non-priced benefits to users. To be successful, preventive measures are needed now to slow down decline. Action, rather than study, is needed at this point, although study should continue. Finally, a watershed-wide management plan with participation by representatives of all user groups would be much more effective than several uncoordinated plans developed by individual groups for unconnected segments of the watershed.

Closing

Discussion of future cooperative actions and closing remarks

Patricia L. Pettit[1]

INTRODUCTION

The knowledge shared and the energy generated by this symposium should not be lost as we leave for our homes and our jobs. We have a great wealth of experience, knowledge, and energy assembled. How can we continue to communicate with each other, share information, involve others, and influence decision makers? The steering committee for this symposium in hopes of stimulating continued cooperation and collaboration included the "Commitment to Action and Feedback Form" with the agenda. Our hope is you will fill out the form and leave it with the steering committee. We will also spend a little time brainstorming ideas together using the feedback form as a guide. The results of these two efforts will be published with the proceedings. The coalition of sponsors for this symposium will work together to implement those that seem the most promising and effective. Your ideas on characteristics for desired future conditions, monitoring, research, outreach and education will be published for all interested groups and agencies to use when planning for further collaborative actions.

RESPONSE AND FEEDBACK

The result of the two response and feedback efforts are listed below. Ideas listed under (A) are from the interactive session with the audience, those listed under (B) are from the commitment to action and feedback form.

1. **What key characteristics should be used to describe desired future conditions for Southwestern Riparian Ecosystems?**

   A. Geo-morphology of stream. Bio-diversity. Fluvial processes. Ecological condition of vegetation. Continuity or connectedness. Role of disturbance. Sustainable use. Society's long range goals.

   B. This is an on-going process involving constant interaction of all factions. Set 5 to 10 year goals and hope for sensitive people close to the land who will sound an alarm when damaging decisions are made. Constant surveillance is essential. Sustainable use and minimal modification, with an emphasis on maintaining natural flows in adjacent streams and rivers. Healthy, functional characteristics such as native vegetation, hydrologic conditions, wildlife communities, and human uses. Vegetative cover and composition, vegetated banks verses raw banks. Hydrograph should be as close to natural as possible. Water quality including turbidity, channel bottom conditions. Landscape setting as a reflection of ecological potential, based on geomorphic, fluvial, and ecological processes. Ecological condition of vegetation. Functioning of ecological processes. Species composition, connectedness, and regeneration.

2. **What parameters should be monitored to measure progress in moving toward the desired future conditions? How frequently should they be monitored?**

   A. Water quality, surface and ground water, macro-invertebrates, nutrient cycling and productivity, 4-5 year frequency. Water quantity. Changes in vegetation species, composition, cover, and structure. Vegetative productivity. Vertebrate response to change, aquatic and terrestrial. Soil produc-

[1] *President, New Mexico Riparian Council, Albuquerque, NM.*

tivity and condition. Functional processes. Hydrograph. Landscape scale setting. Human population changes and changes in land use. Livestock use. Monitoring parameters must be prescribed using cost as a criteria.

B. Species diversity, density, and abundance. Master planning and ordinances in communities containing riparian areas. Vegetation composition, regeneration and utilization - 2 to 5 years. Bank cover and stability, and channel conditions - 2 to 5 years. Water quality including nutrients, and turbidity, and water quantity. Surface soil erosion - 2 to 5 years. Hydrograph every 5 years. Water table height and chemistry - 4 times/year. Soil structure, texture, moisture, nutrients, and biological activity. Surface litter buildup. Productivity of woody and herbaceous vegetation. Activity of key animal populations. Monitor everything that time, personnel, and skills allow. Emphasis will change as processes in the system change over time. Ecological status and processes. Management actions that impact or restore riparian conditions. Percentage of native vegetation and exotic vegetation. Current verses desired ecological condition.

3. How can we bring people and groups together on a common vision for Southwestern Riparian Ecosystems?

A. Poster display at the balloon fiesta. Actively solicit involvement from people not currently involved. Publish newsletter more frequently and with wider distribution. Integrate contrasting views, find links and commonalities. Public forums. Key demonstration projects involving collaborators. Tours for the media, public, and legislators. Educational brochures for primary and secondary educators. Person to person contacts. State fair exhibits. Poster or exhibit for public places. Outreach through other professional organizations.

B. Keep the issue of riparian values constantly before the public. Actively solicit input from people and groups who are not currently involved. Pick up the phone and call them, ask them why they are not involved and what it would take for them to be involved. Place reasonable agency people within the communities and let them work at that level. Networking via publications and dialogue groups. Involve elected officials especially at the local, county, and tribal level. Develop demonstration projects to educate laypeople and recruit support for riparian preservation. Provide a neutral forum such as the N.M. Riparian Council or local watershed coalition. Develop outreach programs. Have meetings/workshops in different parts of the state. Publicize activities. Develop good press relations. Encourage an inclusive membership from all public/private sectors. Cooperate with other groups in monitoring and information exchange. Start with individual groups, so they can express their concerns before trying to integrate.

4. What are additional research needs for Southwestern Riparian Ecosystems?

A. Basic ecology. Big game and other game effects. Fire effects. Development of defensible monitoring protocols. More on climate fluctuations. Rate of invasion by exotics, and their impact. Historic and pre-historic conditions. Protocol for research and management to work together on solutions. Effects of land use and management problems. Comprehensive literature review of research in Southwestern Riparian. Develop restoration ecology techniques, implement and monitor response. Instream flow requirements. Social valuation.

B. How to manipulate surface and subsurface flows to restore wet meadow conditions. Track how long it takes riparian areas to recover when cattle are totally and partially excluded. Grazing strategies compatible with desired future conditions. Functional roles of invertebrates, amphibians, and reptiles. Role of disturbances such as fire, drought, big game, and exotic species. Effects of urban growth on riparian function. Age assessment of fluvial deposits/ erosion cycles to better judge conditions in terms of natural fluctuations. Effects of un-

mitigated overland flows from roads and developments. Linkages of soil, water, vegetation, fish and wildlife.

5. **What suggestions do you have for making information on Riparian Area Management more available?**

   A. Clearing house for information. Field trips for the general public. More widely published information. Integration into the N.M. Water Camp agenda. Logistical help for workshops. Funding school buses for field trips. Speakers bureau. Education for elected officials. Informational videos.

   B. Publicize more widely, and keep costs down. Involve locals, involve communities, allow laypeople to gather data. Sacrifice a little scientific rigor for the opportunity to work with the people in the specific area. Periodic updates of the Riparian Bibliography, include other media. Monthly publication announcing events, meetings, status reports on research, contact people and funding sources. Distribute information to grassroots people and organizations, educate the politicians within your area. Create a riparian video for Public Broadcasting System. Use available tools such as the livestock weekly which reach target audiences. Work closely with the editor of "Dialogue". Multi-use data base and Internet connection. Have positive field trips. Hands on workdays.

6. **How can you help bring diverse interests together on a common vision and action plan for Southwestern Riparian Ecosystems?**

   B. Active membership and participation in N.M. Riparian Council activities. As an author of articles for publication. Call people who are not actively participating now, but, who should be. Work on a day to day basis locally. Use the people who help you to develop good local plans, then involve them in seeking broader coordination. Form a dialogue group to bring together diverse stakeholders to share information. Focus on the clean water, air, and land that we all need to live. Get together with local conservation/environmental groups and government agencies with riparian concerns. Listen to those around us. First establish a range of visions, assess where the majority lies, manage for the majority's vision. Develop local coalitions. Make information about watershed associations available. Provide incentive money and/or technical assistance.

7. **What suggestions do you have for an action plan?**

   A. Tie in with existing resources, experts and knowledgeable, concerned groups. Reintroduce a New Mexico Riparian Conservation Bill in the 1997 Legislature. Prepare Riparian brochures. Develop a Riparian Lesson Plan. Prepare a public display.

   B. Get involved with environmental education. Promote dialogue between resource users, environmentalists, agencies, and legislators. Develop a multi-agency/international action plan for the Rio Grande Riparian Ecosystem.

Appendix

List of attendees

Symposium participants

Albert Abee
Bureau of Land Management
Washington,D.C.

Dan Baggao
Bureau of Land Management
P.O. Drawer 1857
Roswell, NM 88202

Malchus Baker
USDA Forest Service
Rocky Mtn Experiment Station
2500 Pine Knoll
Flagstaff, AZ 86001

John Baldwin
USDA Forest Service
Gila National Forest
P.O. Box 8
Glenwood, NM 88039

Richard Becker
Albuquerque WildlifeFoundation
1005 Indiana SE
Albuquerque, NM 87108

Teri Bennett
Earth Data Analysis Center
2500 Yale Blvd SE
Albuquerque, NM 87106

Patricia Boness
USDA Forest Service
2323 E. Greenlaw Ln
Flagstaff, AZ 86004

Gilbert Borrego
New Mexico State Land Office
P.O. Box 1148
Santa Fe, NM 87504-1148

John Bowerman
White Light Consulting
P.O. Box 8587
Las Cruces, NM 88006

Michael Bradley
NM Natural Heritage Program
2500 Yale SE Suite 100
Albuquerque, NM 87131

Noreen Breeding
1008 Parkland Pl SE
Albuquerque, NM 87108-4327

Hal Brockman
NRCS
6200 Jefferson NE
Albuquerque, NM 87109

Elsa Bumstead
Santa Ana Pueblo
Natural Resources Coordinator
2 Dove Rd
Bernalillo, NM 87004

Bob Calamusso
USDA Forest Service
Rocky Mtn Experiment Station
2500 Pine Knoll
Flagstaff, AZ 86001

Curtis Carley
USDI Fish and Wildlife Service
500 Gold Avenue SW RM 4012
Albuquerque, NM 87103

Karen Cathey
USDI Fish and Wildlife Service
2105 Osuna NE
Albuquerque, NM 87113

Elizabeth Cervantes
USDI Fish and Wildlife Service
2105 Osuna NE
Albuquerque, NM 87113

Steve Chambers
USDI Fish and Wildlife Service
P.O. Box 1306
Albuquerque, NM 87103

Clarence Chavez
USDA Soil Conservation Service
704 South Sunset
Roswell, NM 88201

George Chavez
NRCS
6200 Jefferson
Albuquerque, NM 87031

Matt Chew
Arizona State Parks Board
1300 W Washington
Phoenix, AZ 85007

Alice Chung-MacCoubrey
USDA Forest Service
Rocky Mtn Experiment Station
2205 Columbia SE
Albuquerque, NM 87106

Carolyn Cleveland
City of Albuquerque Open Space Division
P.O. Box 1293
Albuquerque, NM 87103

Joneen Cockman
P.O. Box 5002, WPB
Las Cruces, NM 88003

Alice Cohen
USDA Forest Service
Gila National Forest
3005 E. Camino Del Bosque
Silver City, NM 88061

Jim Cooper
USDA Forest Service
517 Gold Avenue SW
Albuquerque, NM 87102

Francisco Cortez
USDA Forest Service
Tres Piedras Ranger District
P.O. Box 38
Tres Piedras, NM 87577

Cliff Crawford
Department of Biology,
University of New Mexico
Albuquerque, NM 87131

Saul Cross
Department of Energy
103 Carolino Canyon,
Tijeras, NM 87059

Susan Curtis
USDA Forest Service
Coconino National Forest
2323 E. Greenlaw Ln
Flagstaff, AZ 86004

Cassandra D'Antonio
US Army Corps of Engineers
P.O. Box 1580
Albuquerque, NM 87103

David Dall
USDI Fish and Wildlife Service
500 Gold Avenue SW RM 4012
Albuquerque, NM 87103

David Deardorff
New Mexico State Land Office
P.O. Box 1148
Santa Fe, NM 87504-1148

Melanie Deason
New Mexico Environment Department
1190 St. Francis Dr.
Santa Fe, NM 87502

Leonard DeBano
University of Arizona
Tucson, AZ

James Dee
Bureau of Indian Affairs
P.O. Box 181
Chinle, AZ 86503

William DeRagon
USA Corps of Engineers
P.O. Box 1580
Albuquerque, NM 87103-1580

James Derrick
USDA Forest Service
Lakeside Ranger District
RR3, Box B-50
Lakeside, AZ 85925

Andy Dimas
Bureau of Land Mangement
P.O. Box 27115
Santa Fe, NM 87502

Paula Durkin
UNM Biology Dept
2500 Yale Blvd
Albuquerque, NM 87131

Kim Edlund
NMED
1190 St Francis Dr.
Santa Fe, NM 87502

Kim Eichhorst
UNM Biology Dept
827 Zuni Rd SE
Albuquerque, NM 87127

Lisa Ellis
Department of Biology
University of New Mexico
Albuquerque, NM 87131

Jerry Elson
USDA Forest Service
157 Sunrise Rd
Santa Fe, NM 87505

Francisco Escobedo
USDA Forest Service
517 Gold Ave SW
Albuquerque, NM 87102

Bill Falvey
Bureau of Land Management
1235 La Plata Highway
Farmington, NM 87401

Deborah Finch
USDA Forest Service
Rocky Mtn Experiment Station
2205 Columbia SE
Albuquerque, NM 87106

James Findley
UNM Biology Department
P.O. Box 44
Corrales, NM 87048

Carl Fleming
National Park Service
P.O. Box 73
Big Bend National Park, TX 79834

Mark Flora
National Park Service
P.O. Box 25287
Denver, CO 80225-0287

Juan Gallegos
USDA Forest Service
Coconino National Forest
2323 E. Greenlaw Ln
Flagstaff, AZ 86004

Dennis Garcia
New Mexico State Land Office
P.O. Box 1148
Santa Fe, NM 87504-1148

Bill Goodman
USDA Forest Service
208 Cruz Alta Rd
Taos, NM 87571

Nancy Gordon
Engineers, Inc.
P.O. Box 5080
Silver City, NM 88062

Frank Graves
USA Corps of Engineers
P.O. Box 1580
Albuquerque, NM 87103-1580

Amanda Guay
USDA Forest Service
Coconino National Forest
2323 E. Greenlaw Ln
Flagstaff, AZ 86004

Phil Guertin
University of Arizona, 325 BSE
Tucson, AZ 85721

Denise Hampton
USDA Forest Service
714 Main Street
Clayton, NM 88415

Audrey Hansen
Rio Grande Nature Center
9904 Menaul NE #G-8
Albuquerque, NM 87112

Brian Hanson
USDI Fish and Wildlife Service
2105 Osuna NE
Albuquerque, NM 87113

Jay Hart
City of Albuquerque
Open Space Division
P.O. Box 1293
Albuquerque, NM 87103

Bill Hauck
UNM
2817 Cutler Ave NE
Albuquerque, NM 87106

Susan Hill
NMED-SWQB
Box 26110
Santa Fe, NM 87502

Steve Hofstad
UNM Water Resources Admin
941 Buena Vista SE, G208
Albuquerque, NM 87106

Keary Howley
City of Albuquerque
Open Space Division
P.O. Box 1293
Albuquerque, NM 87103

Bonney Hughes
NMED Surface Water Qual Bureau
P.O. Box 26110
Santa Fe, NM 87502

Debbie Hughes
PRNRRO
163 Trail Canyon Rd
Carlsbad, NM

Mering Hurd
USDA Forest Service
316 E. Myrtle Street
Boise, ID 83702

James Hurja
USDA Forest Service
Coconino National Forest
2323 E. Greenlaw Ln
Flagstaff, AZ 86004

Andy Iskra
Bureau of Land Management
1108-D Nakomis NE
Albuquerque, NM 87112

Roy Jemison
USDA Forest Service
Rocky Mtn Experiment Station
2500 Pine Knoll
Flagstaff, AZ 86001

Robert Jenks
New Mexico State Land Office
P.O. Box 1148, Sa48
Albuquerque, NM 87504-1148

David Johnson
New Mexico Parks and Recreation Division
P.O. Box 1147
Santa Fe, NM 87509-1149

Janet Johnson
USDA Forest Service
2324 E. McDowell Rd
Phoenix, AZ 85006

Bruce Klinekole
Mescalero Apache Cattle Growers Association
115 Sage NE, Box 152
Mescalero, NM 88340

Monica Klingler
USDA Forest Service
P.O. Box 132
Glenwood, NM 88039

Edward Korzdorfor
NRCS
374 Alexander Blvd Suite G
Albuquerque, NM 87107

Dave Krueper
USDI Bureau of Land Management
1763 Paseo San Luis
Sierra Vista, AZ 85635

Maria Kuhn
New Mexico Environment Dept
1190 St. Francis Dr.
Santa Fe, NM 87502

Sam Kunkle
National Park Service
P.O. Box 728
Santa Fe, NM 87504-0728

Ben Kuykendall
USDA Forest Service
Box 5736
Taos, NM 87571

David Leal
USDI Fish and Wildlife Service
2105 Osuna NE
Albuquerque, NM 87113

Ondrea Linderoth
City of Albuquerque
Open Space Division
P.O. Box 1293
Albuquerque, NM 87103

Steve Loring
NMSU-Agriculture Experiment Station
P.O. Box 30003, Dept. 3BF
Las Cruces, NM 88003

Penny Luehring
USDA Forest Service
517 Gold Ave SW
Albuquerque, NM 87102

Mike Lujan
USDA Forest Service
Pecos/Las Vegas Ranger District
P.O. Drawer 429
Pecos, NM 87552

Barney Lyons
USDA Forest Service
2113 Osuna Rd NE Suite A
Albuquerque, NM 87113

Elise McLaughlin
EMNRD-MMD
2040 S. Pacheco
Santa Fe, NM 87505

Alvin Medina
USDA Forest Service
Rocky Mtn Experiment Station
2500 Pine Knoll
Flagstaff, AZ 86001

John Moeller
USDA Forest Service
517 Gold Ave SW
Albuquerque, NM 87102

Roger Mongold
USDA Forest Service
Box 1796
Cuba, NM 87013

Edward Montoya
Navajo Fish and Wildlife
P.O. Box 1480
Window Rock, AZ 86515

Karen Mora
USDA Forest Service
Rocky Mtn Experiment Station
3825 E. Mulberry
Fort Collins, CO 80524

Esteban Muldavin
UNM Natural Heritage Program
2500 Yale Blvd
Albuquerque, NM 87131

M.J. Mund-Meyerson
UNM Dept of Biology
University of New Mexico
Albuquerque, NM 87131

Lewis Munk
Soil and Water West Inc.
1700 Southern Blvd.
Rio Rancho, NM 87124

Daniel Neary
USDA Forest Service
Rocky Mtn Experiment Station
2500 S. Pine Knoll
Flagstaff, AZ 86001

Robin Nieto
USDA Forest Service
Mt. Taylor Ranger District
Cibola National Forest
1800 Lobo Canyon Rd
Grants, NM 87020

Michael Norte
New Mexico Trout
7849 Quintana NE
Albuquerque, NM 87109

Phil Norton
Bosque del Apache
P.O. Box 1246
Socorro, NM 87801

Tom Olsen
Thomas Olsen Association
Box 1016
Flagstaff, AZ 86002

Mary Orr
USDA Forest Service
Española Ranger District
P.O. Drawer R
Española, NM 87532

Steve Overby
USDA Forest Service
Rocky Mtn Experiment Station
2500 S. Pine Knoll Drive
Flagstaff, AZ 86001

Richard Pacheco
Western Network
616 Don Gaspar
Santa Fe, NM 87501

Richard Periman
USDA Forest Service
Rocky Mtn Experiment Station
2205 Columbia SE
Albuquerque, NM 87106

Patricia Pettit
Tree New Mexico
P.O. Box 81827
Albuquerque, NM 87198

Deborah Potter
USDA Forest Service
517 Gold Avenue SW
Albuquerque, NM 87102

Carol Raish
USDA Forest Service
Rocky Mtn Experiment Station
2205 Columbia SE
Albuquerque, NM 87106

Jeff Redders
USDA Forest Service
San Juan National Forest
701 Camino Del Rio
Durango, CO 81301

Sarah Rinkevich
USDI Fish and Wildlife Service
2105 Osuna NE
Albuquerque, NM 87113

John Rinne
USDA Forest Service
2500 Pine Knoll
Flagstaff, AZ 86001

Wayne Robbie
USDA Forest Service
Coconino National Forest
517 Gold Ave SW
Albuquerque, NM 87102

John Rosapepe
New Mexico Environment Dept
1190 St. Francis Dr.
Santa Fe, NM 87502

Natalie Runyan
Animas Foundation
HC 65, Box 179-B
Animas, NM 88020

S. D. Schemnitz
Dept of Fish and Wildlife Science
NMSU,P.O. Box 30003
Las Cruces, NM 88003

Paula Schmidt
USDA Forest Service
Coconino National Forest
2323 E. Greenlaw LN
Flagstaff, AZ 86004

Robert Schmidt
USDA-SCS
Box 11232
Reno, NV 89510

Dan Scurlock
Wingswept Reserach, Inc.
1333 Arcadian Tr. NW
Albuquerque, NM

Steve Sebring
USDA Forest Service
517 Gold Ave SW
Albuquerque, NM 87102

Mark Sewards
UNM Biology Dept.
University of New Mexico
Albuquerque, NM 87131

Daniel Shaw
Bosque Prep School
P.O. Box 474
Placitas, NM 87043

Doug Shaw
USDA Forest Service
P.O. Box 662
Corrales, NM 87048

Harley Shaw
General Wildlife Services
P.O. Box 370
Chino Valley, AZ 86323

Tom Shrader
US Bureau of Reclamation
P.O. Box 61470
Boulder City, NV 89006-1470

Bruce Sims
USDA Forest Service
P.O. Box 201
Tesuque, NM 87574

John Slown
City of Albuquerque
Parks and General Services
P.O. Box 1293
Albuquerque, NM 87103

Denise Smith
USA Corps of Engineers
P.O. Box 1580
Albuquerque, NM 87103-1580

Charles Spann
USDA Forest Service
517 Gold Ave SW
Albuquerque, NM 87102

Ronald Stein
Prescott National Forest
344 S. Cortez St.
Prescott, AZ 87301

Pete Stewart
USDA Forest Service
3005 E. Camino del Bosque
Silver City, NM 88061

Pearl Stratton
NRCS
4374 Alexander Blvd Suite G
Albuquerque, NM 87107

Julie Stromberg
Center for Environmental Studies
Arizona State University
Box 873211
Tempe, AZ 85287-3211

Tom Subirge
Apache-Sitgreaves National Forest
P.O. Box 640
Springerville, AZ 85938

Russell Suminski
USDA Forest Service
P.O. Box 7184
Grants, NM 87020

Joseph Tainter
USDA Forest Service
Rocky Mtn Experiment Station
2205 Columbia SE
Albuquerque, NM 87106

Art Telles
USDA Forest Service
Pecos/Las Vegas Ranger District
P.O. Drawer 429
Pecos, NM 87552

Cary Thompson
USDA Forest Service
5079 N. Highway 89
Flagstaff, AZ 86004

Roberta Thomspon
NRCS
6200 Jefferson St. NE
Albuquerque, NM 87109

Joan Thullen
National Biological Services
P.O. Box 25007, D-8220
Denver, CO 80225-0007

Carol Torrez
USDI Fish and Wildlife Service
2105 Osuna NE
Albuquerque, NM 87113

David Tubb
USDA Forest Service
Pleasant Valley Ranger District
P.O. Box 450
Young, AZ 85554

Gail Tunberg
USDA Forest Service
Santa Fe National Forest
P.O. Box 1689
Santa Fe, NM 87504

Rebecca Tydings
Rio Grande Nature Center
2901 Candelaria NW
Albuquerque, NM 87107

Greg Valdez
USDA Forest Service
Carson National Forest
664 East Broadway
Bloomfield, NM 87413

Maurice Valett
UNM Dept of Biology
University of New Mexico
Albuquerque, NM 87131

Dwain Vincent
Bureau of Land Mangement
6604 Hensch Avenue NE
Albuquerque, NM 87109

K. Wadsworth
3 Aula Court
Santa Fe, NM 87505

Roby Wallace
The Nature Conservancy
212 E. Marcy
Santa Fe, NM 87501

Yong Wang
USDA Forest Service
Rocky Mtn Experiment Station
2205 Columbia SE
Albuquerque, NM 87106

Mara Weisenberger
USDI Fish and Wildlife Service
P.O. Box 756
Las Cruces, NM 88004

Bill Welch
League of Women Voters
3308 Morris NE Apt 12
Albuquerque, NM 87111

Carl White
University of New Mexico
Department of Biology
Albuquerque, NM 87131

Jeff Whitney
USDI Fish and Wildlife Service
2105 Osuna NE
Albuquerque, NM 87113

Peter Wilkinson
NMED
1190 St. Francis Dr.,
Santa Fe, NM 87502

H.A. Wilmeth
P.O. Box 1321
Silver City, NM 88062

Patricia Woodruff
General Wildlife Services
P.O. Box 370
Chino Valley, AZ 86323

Debra Yazzie
Navajo Fish and Wildlife
P.O. Box 1480
Window Rock, AZ 86515

Bill Zeedyk
P.O. Box 582
Sandia Park, NM 87047

Charlotte Zurof
League of Women Voters
5015 Prospect NE
Albuquerque, NM 87110

Printed on recycled paper

Rocky Mountains

Southwest

Great Plains

U.S. Department of Agriculture
Forest Service

Rocky Mountain Forest and Range Experiment Station

The Rocky Mountain Station is one of eight regional experiment stations, plus the Forest Products Laboratory and the Washington Office Staff, that make up the Forest Service research organization.

RESEARCH FOCUS

Research programs at the Rocky Mountain Station are coordinated with area universities and with other institutions. Many studies are conducted on a cooperative basis to accelerate solutions to problems involving range, water, wildlife and fish habitat, human and community development, timber, recreation, protection, and multiresource evaluation.

RESEARCH LOCATIONS

Research Work Units of the Rocky Mountain Station are operated in cooperation with universities in the following cities:

Albuquerque, New Mexico
Flagstaff, Arizona
Fort Collins, Colorado*
Laramie, Wyoming
Lincoln, Nebraska
Rapid City, South Dakota

*Station Headquarters: 240 W. Prospect Rd., Fort Collins, CO 80526